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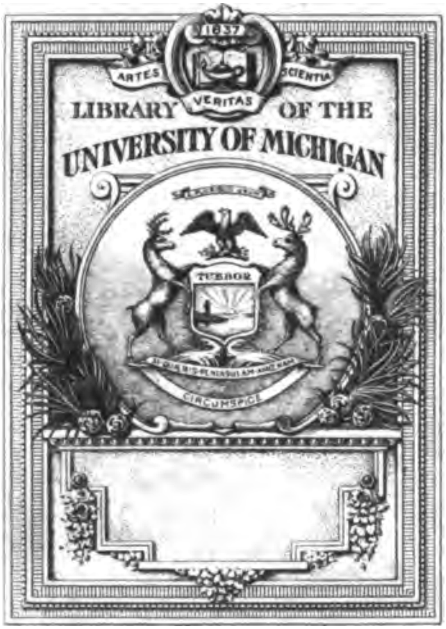
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APPLIED ELECTROCHEMISTRY AND WELDING

A PRACTICAL TREATISE ON COMMERCIAL CHEMISTRY, THE
ELECTRIC FURNACE, THE MANUFACTURE OF OZONE AND
NITROGEN BY HIGH-TENSION DISCHARGES, AND
THE APPLICATIONS OF ELECTRIC, GAS,
AND CHEMICAL WELDING TO MAN-
UFACTURING AND REPAIR
WORK

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CHICAGO
1920

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INTRODUCTION

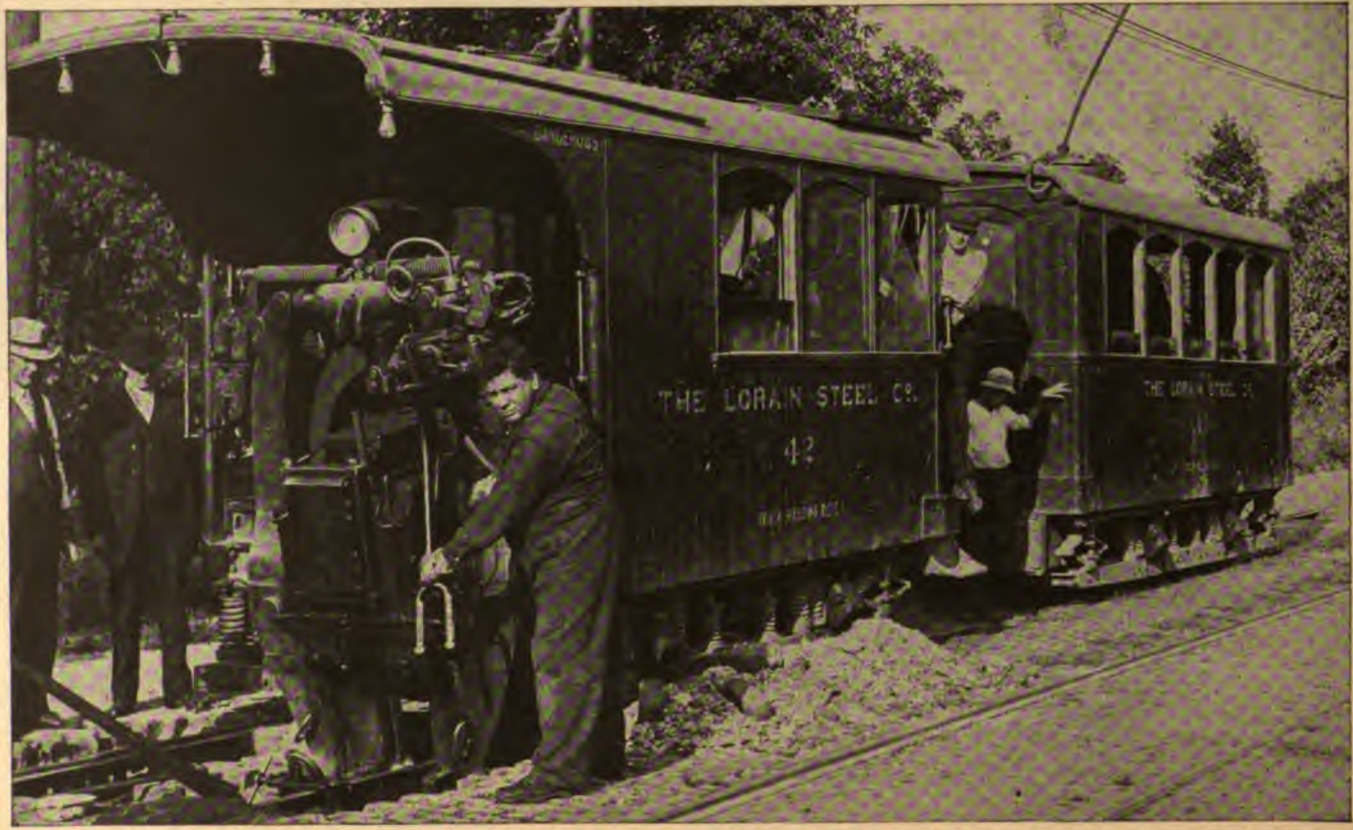
THE principles of Electrochemistry are almost as old as the science of electricity itself. The phenomenon of electrolysis was discovered in 1800, and its laws were experimentally determined by Faraday in 1833; again the electrolytic cell, with its simple electrodes and conducting liquid, was very early used to accomplish the dissociation of chemical compounds in the same manner as it is now used in chemical industries; the electric furnace was really discovered almost simultaneously with the arc lamp and in its essentials is identical with it.

¶ The cheapening of electrical power and the increased use of the products involved have been largely responsible for the progress along these lines and, today, the preparation of electrolytic copper is a great industry; hydrogen and oxygen gases are now obtained by the electrolytic decomposition of water; and the method of electrolyzing fused aluminum oxide has brought the price of aluminum to a practical basis. Again, by means of the electric furnace, several highly resisting chemical reductions have been accomplished and methods have been perfected for the manufacture of calcium carbide, silicon products, carborundum, graphite, and steel.

¶ Welding, one is rather inclined to think, is an unimportant process applied exclusively to the repairing of broken down machinery, but one glance at this section in the volume shows what a commanding position the electric arc, butt, and spot welders are taking in the manufacturing world, and gives a clear idea of the applications of gas and thermit welding to all sorts of processes which are usually supposed to be purely machine operations..

¶ Finally, when by the aid of intense electrical discharges in air, even the nitrogen of the atmosphere is made available for our use, the results seem to approach the miraculous. To think of the world's supply of nitrates being augmented from the very atmosphere itself seems more like a dream of a Jules Verne or a Wells, than an actual twentieth century accomplishment.

¶ All of these scientific marvels are intensely interesting and the treatment has been made exceedingly practical by the authors. The material is written in a clear readable style and is designed to appeal to both the trained engineer and the layman. It is the hope of the publishers that a study of this volume may widen the acquaintance of many readers with this branch of industrial electricity and stimulate their interest in the general scientific development of the world.



TRACK WELDING MACHINE IN OPERATION

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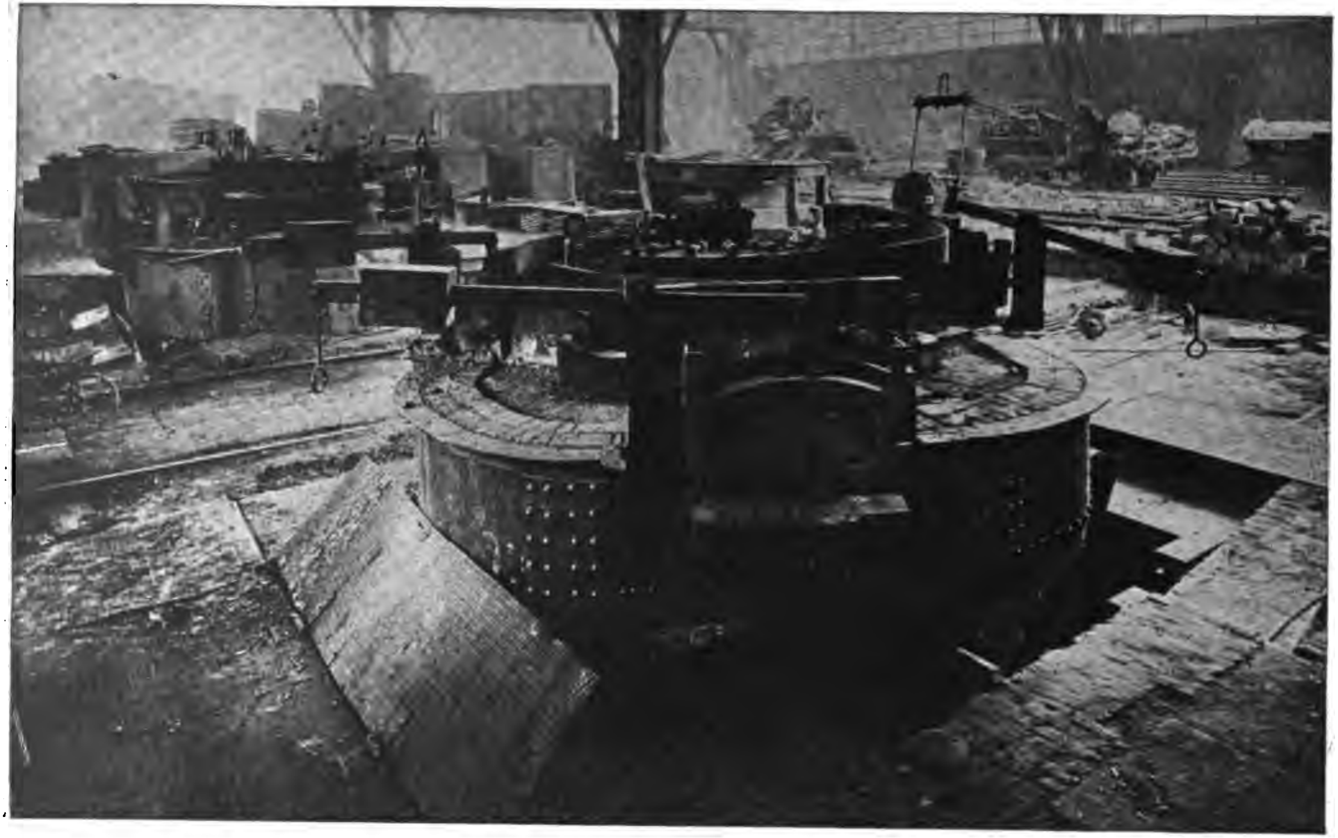


VIEW OF ROECHLING-RODENHAUSER ELECTRIC FURNACE

This furnace is being used in an iron foundry and is capable of reaching a temperature of 3200° F.

Photograph by Underwood & Underwood, New York

PART I

APPLIED ELECTROCHEMISTRY

INTRODUCTION

Chemical Reactions. Chemical reactions are frequently, if not in fact almost universally, associated with changes in electrical energy. The science and art of electrochemistry deal with the relationship of electrical and chemical forms of energy. It is well known that many chemical reactions take place with the liberation of energy in the form of heat; thus when coal burns, combining with the oxygen of the air, there is a liberation of heat energy. Other chemical changes involve an absorption of heat energy, that is, heat must be applied to materials in order to cause certain reactions to take place. The formation of calcium carbide is an example of the production of a useful compound by heating lime and carbon to a high temperature. All chemical reactions may be classified as *endothermic* (heat-absorbing) or *exothermic* (heat-liberating).

Numerous chemical transformations also occur with a liberation of electrical energy, a fact upon which are dependent the various types of primary cells or electric batteries. Electrical energy may, on the other hand, be made to produce chemical changes by the passage of electric current through an electrolyte, and this finds practical application in various forms of electrolytic cells.

Storage batteries constitute an important class of electrical apparatus, consisting of a certain combination of metals and electrolyte in which the electrochemical action is reversible, that is, in passing current through the battery in one direction certain chemical changes take place, or the battery is charged, and these chemical reactions take place in a reverse direction when the current is allowed to flow in a reverse direction, as when the battery is discharged.

Range of the Subject. The fundamental units and principles of electricity, the elementary principles of electrochemical action, the primary cell, and the secondary, or storage, cell have already been considered in previous articles, and consequently this article will be confined to a consideration of the wider field of applied electrochemistry, dealing with the more important practical uses of electrical energy in producing useful chemical transformations.

Electrical energy may be applied to materials by various methods, the more important of which are the following:

(1) Electrolysis, or the electrolytic change brought about by the passage of a direct current through an electrolyte.

(2) Electrothermics, or the production of chemical change through the heat effect produced by electrical means.

(3) Electrical discharge in gases.

ELECTROLYSIS AND ITS APPLICATIONS

ELECTROCHEMICAL THEORY

KINDS OF CONDUCTORS

All materials may be divided, first, into two classes, depending upon whether or not they conduct electrical current. If they conduct, they are called "conductors" and if they do not, they are designated as "insulators". In turn, materials which conduct may again be subdivided into two more classes commonly designated: *metallic conductors*, or *conductors of the first class;* and *electrolytic conductors*, or *conductors of the second class.*

It is important that as a basis for the study of electrolysis a clear idea be acquired as to the distinctive differences between metallic and electrolytic conductors.

Metallic Conductors. As implied by the name, *metallic conductors*, the metals belong to this class; and in addition to the metals and metallic alloys, there are a few other elements and various compounds which conduct in a similar manner and are therefore designated as metallic conductors. In this class of conductors the flow of current produces only a heating effect without producing chemical change.

Non-Metallic Elements. Of the few non-metallic elements which conduct, the most important is carbon, or graphite. Silicon, boron, and selenium are other elements possessing metallic conductivity to some degree.

Chemical compounds do not as a rule conduct metallically. The important exceptions include peroxide of lead, which is a constituent of one of the electrodes in a storage battery; magnetic oxide of iron, Fe_3O_4, which is used as an anode material for electrolytic purposes; sulphides of lead and of silver, various metallic carbides, silicides, borides, etc.

Specific Resistance. The specific resistances of the metals and metal alloys cover a comparatively limited range, a high resistance metal such as mercury having a specific resistance about one hundred times that of the best conductive metals, copper and silver.

It is a characteristic of the metals that the resistance varies in a minor degree with variations in temperature. The resistance usually increases with increase in temperature, or, in other words, the metals have a positive temperature coefficient. With pure metals the temperature coefficient is a constant, i. e., the resistance is approximately proportional to the absolute temperature and, if the resistance be plotted for various temperatures, the line points toward absolute zero, suggesting that if the metals could be cooled to that point they would possess no resistance and thus become perfect conductors.

With the conductive metalloids or non-metals, and with the compounds which conduct metallically, a higher order of specific resistance is encountered as well as a greater variation in temperature coefficient. To the electrochemist, carbon is the most important of these conductors. Its specific resistance varies through a wide range from that of the diamond, which is practically an insulator, to graphite, and then to "metallized" carbon which has a conductivity comparable to that of mercury.

Carbon, such as is used for electrode purposes, may consist of plates made up of finely ground carbon mixed with a binding material, molded into shape and subjected to a high temperature baking. The resistance is dependent upon the quality of the carbon flour, the purity, the nature of the binding material, the pressure of forming, and the baking temperature. The higher the firing temperature used, the lower is the resistance and, by carrying the temperature to the highest attainable value, the material is transformed into a more conductive form known as graphite. The discovery of this method of graphitization by electric heating constitutes one of the most important of the electrochemical discoveries, furnishing not only the basis of a large artificial graphite industry but also supplying an electrode material of inestimable value to the electrochemist.

By data taken from various sources it appears that the commercial forms of electrode carbons have values of specific resistance varying from 3000 to 10,000 microhms per $\overline{\text{cm}}^3$. Graphitized electrodes have a specific resistance of about 800 microhms and the value for metallized carbon has been given as 480 microhms.

The so-called metallic silicon has a specific resistance which varies greatly and in an uncertain manner with increase in temperature. Boron is a conductive material which has only recently been produced but which has created special interest, in that it has a temperature coefficient which is higher than almost any other known substance. A small rod of this material, which shows a resistance of over 5,000,000 ohms at 27° C., shows 46,000 ohms at 180°. The conductivity of selenium likewise possesses interesting characteristics. This element has a high specific resistance, it has a high temperature coefficient and possesses the unusual feature that it changes its resistance notably under the influence of light.

The chemical compounds which conduct metallically are characterized by a high specific resistance and a high negative temperature coefficient.

Electrolytic Conductors. *Characteristics.* The most important characteristic of electrolytic conductivity is that the flow of current produces a chemical transformation. The detection of a chemical change does not, however, constitute an infallible means of determining whether a material should be placed in this class, since under certain conditions the resultant chemical change may be so slight as to avoid detection. Faraday concluded that certain fused chlorides, for example, conducted metallically, because he could detect no appreciable decomposition. The conclusion was probably erroneous, due to the fact that the products which were liberated immediately reunited to form the original substance.

Electrolytic conductors invariably consist of definite chemical compounds. It should be borne in mind that, as pointed out under metallic conductors, not all chemical compounds which conduct are electrolytic conductors.

Classification. Electrolytic conductors may be either fused materials or certain solutions of materials in water or other solvents. Some evidence of electrolytic conductivity has been detected in a few solid compounds, but this phenomenon is of little importance from the practical standpoint. It is with liquid conductors that electrolysis commercially applied has to deal and for practical purposes these liquid conductors may be placed in three divisions:

(1) Electrolytes consisting of substances dissolved in water.

(2) Electrolytes consisting of substances dissolved in solvents other than water.

(3) Electrolytes consisting of chemical compounds in a state of fusion.

The first group is the one of the greatest importance, since water is a great universal solvent, which, on account of its abundance and low cost and great solvent properties, furnishes an essential material in most industrial electrolytic processes. Non-aqueous solutions, while attracting much interest from the theoretical and scientific points of view, have as yet few technical applications. A more extensive use of these solvents, however, may safely be anticipated as a result of future development.

Electrolytes consisting of fused materials have important technical applications in industries such as the manufacture of aluminum, sodium, magnesium, and calcium.

Water, in a high state of purity, possesses very little conductive power; in fact it is practically an insulating material. Kohlrausch gives a specific resistance of 25,000,000 ohms per $\overline{\text{cm}}^3$ for freshly distilled water. On accumulating impurities by exposure to the air for some time, the resistance may drop to one-twentieth of this amount.

Similarly, sulphuric acid, in a condition of absolute purity, has an exceedingly high specific resistance, tending to place it among the insulators. If, however, a certain amount of these two non-conductive substances be mixed together, the result is a material which has a power of conducting to a high degree. The question has naturally arisen as to whether it is the acid under the influence of the water or the water as influenced by the acid, or a combination of both, which produces the conductive power. In settling this point, we would be led into the realm of speculation and, for practical purposes in working with aqueous electrolytes, the common assumption may be followed that it is the substance which is dissolved in the water which possesses the conductive property.

Conductivity. One important characteristic of electrolytic conductors is that the order of conductivity is far lower than that of metallic conductors. The best conducting electrolytes, for example, have a specific resistance at least one million times as great as that of the average metallic conductor.

Another striking characteristic is the negative temperature coefficient which causes the resistance to decrease with increasing temperature.

It should be borne in mind that by no means all of the materials which dissolve in water produce electrolytes. Those chemical substances which on dissolving in water become conductive have been determined by trial and by measurements. Sugar and common salt are both soluble in water. The former, however, produces no electrolytic conductivity, while the latter does.

It has been found by trial that, in general, solutions of inorganic acids, salts, and bases conduct electrolytically, while the neutral organic compounds in solution do not conduct.

The degree of conductivity of an electrolyte depends upon a number of factors, including the chemical composition of the dissolved substance, the amount of such substance in solution, and the temperature.

A quantitative study of the relationship between the conductivity of a solution of a given substance and the amount of substance dissolved, reveals interesting and important features and furnishes the basis upon which modern theoretical views of electrolytic dissociation and conduction are based. However, for practical purposes of an elementary text, it may not be necessary to follow this line of study here.

THE ELECTROCHEMICAL CELL

Definitions. An *electrochemical cell* is a form of apparatus in which all industrial electrolytic processes are carried out. It may be defined as a combination of two metallic conductors, constituting the *electrodes*, and an electrolytic conductor, constituting an *electrolyte* which joins the electrodes. A suitable containing vessel is also an essential part.

The *anode* is the electrode at which the current enters the electrolyte, and the *cathode* is the electrode at which the current leaves the electrolyte.

The cell is *inactive* if no current flows, and it becomes *active* when the current passes, which in turn means that to be active it must be connected to an external source of electrical energy. This external energy may be obtained from any generator of direct current, such as a primary battery, a storage battery, or a dynamo.

Action Inside the Cell. *Diagram of Circuit.* A typical diagram of an active cell is shown in Fig. 1, where *d* is the dynamo, or other source of current; *r* is a rheostat for regulating the amount of current, or current density; *i* is an ammeter for measuring the current; and *v* is a voltmeter for measuring the voltage at the cell terminals; *s* is a switch for opening or closing the circuit. The arrows indicate the direction of the flow of current; *a* is the anode, and *c* the cathode.

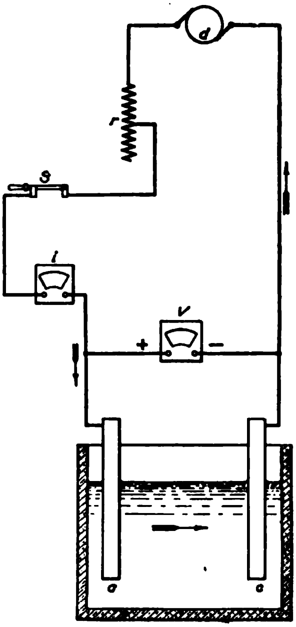


Fig. 1. Diagram of Electrolytic Cell

It will be noted that the positive (+) terminal of the voltmeter is connected to the anode, or positive pole, at which the current enters the cell, while the negative (−) terminal of the voltmeter is connected to the cathode, or negative pole. For this reason it is a common practice to use the terms "positive pole" and "negative pole" in place of the terms "anode" and "cathode", respectively. To avoid confusion, however, it is far better to employ the terms *anode* and *cathode* wherever possible and to learn to know instinctively that the anode designates the surface at which the current enters the electrolyte and that the cathode indicates the surface where the current leaves.

Method of Carrying Current. To determine in just what manner the electrolyte carries the current is the purpose of various theories which are not as yet capable of positive proof. It is a common con-

TABLE I

Positive and Negative Radicals of the More Common Compounds

SUBSTANCE	FORMULA	NEGATIVE RADICAL OR ANION	POSITIVE RADICAL OR CATHION
Aluminum chloride	$AlCl_3$	3Cl	Al
Ammonium chloride	NH_4Cl	Cl	NH_4
Barium chloride	$BaCl_2$	2Cl	Ba
Calcium chloride	$CaCl_2$	2Cl	Ca
Potassium chloride	KCl	Cl	K
Cadmium chloride	$CdCl_2$	2Cl	Cd
Magnesium chloride	$MgCl_2$	2Cl	Mg
Manganese chloride	$MnCl_2$	2Cl	Mn
Sodium chloride	NaCl	Cl	Na
Hydrochloric acid	HCl	Cl	H
Zinc chloride	$ZnCl_2$	2Cl	Zn
Hydrobromic acid	HBr	Br	H
Potassium bromide	KBr	Br	K
Hydriodic acid	HI	I	H
Potassium iodide	KI	I	K
Barium nitrate	$Ba(NO_3)_2$	$2NO_3$	Ba
Calcium nitrate	$Ca(NO_3)_2$	$2NO_3$	Ca
Nitric acid	HNO_3	NO_3	H
Potassium nitrate	KNO_3	NO_3	K
Silver nitrate	$AgNO_3$	NO_3	Ag
Sulphuric acid	H_2SO_4	SO_4	2H
Copper sulphate	$CuSO_4$	SO_4	Cu
Magnesium sulphate	$MgSO_4$	SO_4	Mg
Sodium sulphate	Na_2SO_4	SO_4	2Na
Silver sulphate	Ag_2SO_4	SO_4	2Ag
Zinc sulphate	$ZnSO_4$	SO_4	Zn
Potassium carbonate	K_2CO_3	CO_3	2K
Sodium carbonate	Na_2CO_3	CO_3	2Na
Potassium chlorate	K_2ClO_3	ClO_3	2K
Potassium hydroxide	KOH	OH	K
Sodium hydroxide	NaOH	OH	Na
Potassium chromate	K_2CrO_4	CrO_4	2K
Potassium bichromate	$K_2Cr_2O_7$	Cr_2O_7	2K
Potassium cyanide	KCN	CN	K
Potassium ferrocyanide	$K_4Fe(CN)$	Fe(CN)	4K
Potassium silver cyanide	$KAg(CN)_2$	$Ag(CN)_2$	K
Potassium oxalate	$K_2C_2O_4$	C_2O_4	2K
Sodium acetate	$NaC_2H_3O_2$	$C_2H_3O_2$	Na

ception that the current in passing through the electrolyte causes a bodily movement of some of the material in the electrolyte in the direction of the current and of a corresponding amount of other material in the reverse direction. Or, in other words, the materials held in solution dissociate into ions. Those *ions* which travel with the current and are deposited on the cathode are called *cathions* and those which go against the current and are liberated at the anode are *anions*.

Anions and Cathions. In order to determine what action will take place in a cell, it is important to know what materials constitute the anions and cathions.

From a study of chemistry, it is noted that the inorganic compounds such as are taken into solution in water, are composed of what are known as the *metal,* or *positive, radical* and an equivalent *acid,* or *negative, radical.* Table I gives a list of the more common materials with their respective anions and cathions.

From this table it is to be noted that the cathions consist almost entirely of metals, with the addition of the element hydrogen and of the compound NH_4; also that the anions consist of the electronegative elements, such as chlorine, bromine, iodine, and fluorine, and of various compound radicals, such as SO_4, NO_3, CO_3, OH, CrO_4, etc.

Faraday's Laws. The most important laws pertaining to electrolysis are what are known as Faraday's laws. They constitute the basis of all electrochemical calculations, determining just how much chemical action is produced by a given flow of current for a given time. These laws are as follows:

> (1) The amount of chemical effect produced during electrolysis is directly proportional to the product of the current and the time; that is, to the quantity of electricity which flows through the electrolyte.
>
> (2) When a current passes through an electrolyte, bringing about chemical changes at the electrodes, the quantity of each substance formed is directly proportional to the equivalent weight of the substance and to the quantity of electricity which has flowed through the electrolyte.

It is obvious that if one ampere flowing for one minute will deposit a certain amount of copper, two amperes flowing for one minute will deposit twice that amount. Also that the amount which a given current will deposit in ten minutes is ten times as great as will be deposited by the same current in one minute.

Electrochemical Equivalent. By knowing the *equivalent weight,* or, as it is more commonly termed, the chemical equivalent, of the material, the quantity of that material which will be liberated by a known amount of electric current can be readily calculated. Every substance, whether it be a chemical element or a chemical compound, has its *electrochemical equivalent,* just as it has a certain atomic

TABLE II

Constants of the Elements*

Name of Elements	Symbol	Valency	Chemical Constants		Electrochemical Constants			Commercial Constants "Result"	
			Atomic Weights	Chemical Equivalents	Per Coulomb (i. e. per amp. sec.) in mg. per sec.	Per Ampere Hour (i.e. 3600 Coulombs) in grams	Per Faraday (i.e. 96,540 Coulombs), grams	Per 1000 Ampere Years (i.e. 8760 hrs.) in metric tons	Per H. P. Year for one volt in metric tons
Aluminum....	Al	III	27.10	9.03	.09354	.33674	9.033	2.950	2.201
Antimony.....	Sb	III	120.20	40.07	.41509	1.4943	40.067	13.090	9.765
Arsenic.......	As	III	75.00	25.00	.25898	.93233	25.000	8.167	6.093
Barium.......	Ba	II	137.40	68.70	.71166	2.5620	68.700	22.443	16.742
Bromine......	Br	I	79.96	79.96	.82831	2.9819	79.960	26.221	19.561
Cadmium.....	Cd	II	112.40	56.20	.59229	2.1322	56.200	18.678	13.934
Calcium.....	Ca	II	40.10	20.05	.20770	.74772	20.050	6.550	4.886
Carbon.......	C	IV	12.00	3.00	.031077	.11188	3.000	.9801	.7311
Chlorine......	Cl	I	35.45	35.45	.36723	1.3220	35.450	11.581	8.639
Cobalt.......	Co	II	59.00	29.50	.30559	1.1001	29.500	9.637	7.189
Copper.......	Cu	II	63.60	31.80	.32942	1.1859	31.800	10.388	7.749
Fluorine......	F	I	19.00	19.00	.19682	.70855	19.000	6.207	4.630
Gold.........	Au	III	197.20	65.73	.68090	2.4512	65.733	21.473	16.019
Hydrogen.....	H	I	1.008	1.008	.010442	.03759	1.008	.329	3.2456
Iodine........	I	I	126.97	126.97	1.3153	4.7351	126.970	41.479	30.943
Iron..........	Fe	II	55.90	27.95	.28953	1.0423	27.950	9.131	6.812
	Fe	III	55.90	18.63	.19279	.69404	18.633	6.090	4.543
Lead.........	Pb	II	206.9	103.45	1.07164	3.8579	103.450	33.795	25.211
Magnesium...	Mg	II	24.36	12.18	.12617	.45422	12.180	3.979	2.968
Manganese....	Mn	II	55.00	27.50	.28587	1.0291	27.500	9.015	6.725
	Mn	III	55.00	18.33	.18988	.68357	18.333	5.988	4.467
Mercury......	Hg	I	200.00	200.00	2.0718	7.4585	200.000	65.333	48.738
	Hg	II	200.00	100.00	1.0359	3.7292	100.000	32.667	24.370
Nickel........	Ni	II	58.70	29.35	.30404	1.0945	29.350	9.588	7.153
	Ni	III	58.70	19.57	.20273	.72983	19.567	6.393	4.769
Nitrogen......	N	III	14.04	4.680	.048480	.17453	4.680	1.529	1.141
Oxygen.......	O	II	16.000	8.000	.082872	.29834	8.000	2.613	1.949
Platinum.....	Pt	IV	194.80	48.70	.50448	1.8161	48.700	15.909	11.868
Potassium.....	K	I	39.15	39.15	.40555	1.4600	39.150	12.790	9.541
Silicon........	Si	IV	28.40	7.10	.073549	.26478	7.100	2.319	1.730
Silver.........	Ag	I	107.93	107.93	1.11805	4.02498	107.930	35.267	26.309
Sodium.......	Na	I	23.05	23.05	.238775	.859590	23.050	7.530	5.617
Sulphur.......	S	II	32.06	16.03	.16605	59778	16.030	5.237	3.907
Tin..........	Tn	II	119.00	59.5	.61636	2.2189	59.500	19.438	14.501
	Tn	IV	119.00	29.75	.30818	1.1094	29.750	9.718	7.250
Zinc..........	Zn	II	65.40	32.70	.33874	1.2195	32.700	10.683	7.970

*From "Electrothermal and Electrolytic Industries", Ashcroft.

weight; and in fact the electrochemical equivalent is closely associated with the atomic weight.

The *electrochemical equivalent* of a substance is the atomic weight divided by the valence and multiplied by a constant. This constant is a weight of hydrogen which will be liberated by a unit quantity of electric current. This constant is .00001036 grams, being the amount of hydrogen which is liberated by one coulomb or one ampere flowing for one second.

For purposes of practical calculation it is common to express the electrochemical equivalent of a substance in terms of the amount of material which is deposited by one ampere flowing for one hour's time. Table II gives electrochemical equivalents of various common elements.

If, for example, it is desired to know how much copper will be deposited by ten amperes flowing for two hours, a simple calculation based upon the value of copper shown in Table II can be made. It is $10 \times 2 \times 1.1859$, or 23.71 grams. Likewise, the same amount of current will liberate $10 \times 2 \times 1.322$, or 26.44 grams of chlorine.

Cathode Reactions. In observing the changes which take place at the cathode during electrolysis, various phenomena may be noted. If a suitable solution containing copper or nickel is used, copper or nickel will be deposited at the cathode, coating it over and growing to such thickness as is determined by the amount and duration of the current. Likewise, various other metals, such as gold, silver, iron, zinc, cobalt, and cadmium, may be deposited. This furnishes the basis of the electroplating industry. Some of the metals, on the other hand, will not be deposited out in the metallic state; for example, no one has yet succeeded in depositing metallic aluminum, neither can sodium, or potassium, or calcium, or various other highly positive metals be deposited from aqueous solutions. The reason for this is that these electropositive metals, at the instant they are liberated by the current, react chemically with the water to form other compounds. When sodium is deposited, it reacts chemically with the water, in accordance with the following equation:

$$\mathrm{Na} + \mathrm{H_2O} = \mathrm{NaOH} + \mathrm{H}$$

Instead, therefore, of metallic sodium being liberated, hydrogen is evolved and caustic soda is formed in the electrolyte. The electrolytic production of caustic soda and of hydrogen is thereby made possible as a result of electrolytic action supplemented by chemical action.

It should be noted, therefore, that the *cathion* may be deposited directly on the cathode, or it may unite chemically with the electrolyte.

Anode Reactions. In a similar manner the *anions*, upon being liberated, may be deposited on the anode, or may escape as a gas, or may react chemically with the electrolyte, or may unite chemically with the electrode material. Which of these various processes takes place depends largely upon the peculiar characteristics of the material involved. It is important to note that the materials at the instant of liberation are in a particularly active chemical condition, or in the nascent state. Perhaps the most noticeable action at the anode is a tendency for the liberated materials to attack or corrode the anode. Thus, for example, when a sodium chloride solution is electrolyzed between two iron electrodes, the chlorine which is liberated at the anode will attack the iron to form soluble iron chloride; in other words, the iron will go into solution. If it is desired to decompose salt for the production of chlorine, an *insoluble* anode material must be selected. Graphite is particularly serviceable for this purpose and is extensively used for chlorine production.

Soluble and Insoluble Anodes. We have then what are known as *soluble* and *insoluble* anodes, depending upon whether they withstand the action of the electrolysis. As a general rule, the metals are corroded when used as anodes. It is for this reason that deterioration of water and gas pipes takes place in the city streets where leakage current from electric railways flows from the iron surfaces into the earth. Dependent upon the anode solubility, the amount of metal in an electroplating solution is maintained at a constant value, the metal going into solution from the anode at the same rate that it is deposited out at the cathode.

Of the various metals, platinum is the one most commonly used when an insoluble metal is required. Graphite is insoluble in chloride solutions, while it is slowly attacked in certain other solutions. Lead peroxide and the black magnetic oxide of iron, previously referred to as being compounds which conduct metallically, have their principal use in electrolytic work because of their electrochemical insolubility.

ELECTROLYTIC REFINING AND RECOVERY OF METALS

Refining Copper. An important use of the electrolytic cell is found in the refining of certain metals, the most important of which is copper. Copper of high purity is necessary as a conductive material for electric power generation and distribution, and in the early days of the electrical industry, the only source of a sufficiently pure metal was the native metallic copper found in the Lake Superior region and commonly known as "lake" copper. The rapidity of electrical development made this source of supply entirely inadequate and it became necessary to draw upon the enormous deposits of copper ore found in the Western States. By the ordinary metallurgical methods of smelting, however, only an impure grade of copper could be produced, the highest purity not being greatly in excess of 98 per cent. A very small amount of alloying impurity in copper has the effect of greatly reducing its electrical conductivity and, therefore, high purity is of supreme importance. The desire of utilizing these Western ores, therefore, directed attention to the electrolytic method of refining. In fact, practically the only known method of making impure copper available for the electrical industry is by the electrolytic refining methods which have been worked out during the last quarter of a century.

Action in Experimental Cell. A simple experimental cell for refining copper can be constructed easily by dissolving copper sulphate crystals in water, adding a small amount of sulphuric acid, and then passing current through this solution, using an impure copper anode and a copper sheet cathode upon which the pure metal is to be deposited. The amount of copper which is deposited upon the cathode depends mainly upon the amount of current and the time of flow. The SO_4 anion which is liberated at the anode attacks the anode copper, forming copper sulphate and thus replacing the copper which is thrown out at the cathode. The amount of copper which goes into solution should, according to Faraday's laws, be equal to that which is deposited out at the cathode. The resultant action is then simply a transference of the copper from the anode through the solution to the cathode. The refining takes place because certain of the impurities in the anode are insoluble, such for example as silver, gold, and lead. Certain other impurities go into solution in the electrolyte, but are prevented from being deposited at the cathode because copper separates far more easily than do the other elements.

By-Products. The result of this refining operation is that certain of the impurities either remain attached to the anode or settle to the bottom of the cell as what is known as anode slime. Other of the impurities, such as arsenic and iron, gradually accumulate in the electrolyte until such quantity is reached that it becomes necessary either to throw the electrolyte away or put it through a chemical refining operation.

The electrolytic cell for the refining of metals has been likened to a series of screens through which the desired metal is sifted, leaving the impurities behind.

While the principal object in the refining of copper was to get the pure metal, it was soon noted that some of the impurities which settled to the bottom of the tank were of value, these metals being principally gold and silver. The subsequent recovery of these materials from the anode slimes furnished a great source of profit, and, in fact, copper refining has become important not only for the manufacture of pure copper but for the recovery of precious metals as well.

Refining of Metals Other Than Copper. *Silver.* It must not be assumed that, because copper refining by electrolysis is eminently successful, the electrolytic method may be similarly applied to the other metals. In fact the ordinary metallurgical methods are usually superior as to cost and availability. Electrolytic silver refining is carried out to some extent by what is known as the *Moebius* process, in which the anodes or impure silver bars are suspended in a filter cloth sack in an electrolyte consisting of silver nitrate slightly acidified by nitric acid.

From this electrolyte the silver is deposited in a loose crystalline state which tends to grow in tree-like formations toward the anode. To prevent this, each cathode is provided with a wood scraper which periodically removes the crystalline deposit of pure silver. This settles to the bottom of the tank, where it is subsequently removed.

Gold. Gold refining is likewise carried out to a certain extent, the anodes usually containing about 94 per cent of gold, 5 per cent of silver, and one per cent of copper and various other metals. The electrolyte consists of a solution of gold chloride with a small amount of free hydrochloric acid and a trace of gelatin added to improve the physical quality of cathodic deposit.

Baser Metals. While many attempts have been made toward electrolytic refining of common metals, such as zinc, tin, nickel, and iron, the difficulties are usually so great, or the other metallurgical methods so satisfactory, as to make the financial reward insufficient to warrant commercial development. The electrolytic refining of iron seems to offer some possibilities of industrial success, due to a certain demand for a specially high-grade material. Most of the electrolytic iron thus far produced has been used only for experimental purposes and in researches concerning the nature of iron and iron alloys.

From the experiments of the earlier electrochemists with the deposition of lead, there was a general belief that lead could not be deposited electrolytically in anything but a loose and spongy form. As illustrating the value of a detailed study of electrolyte materials, reference may be made to the interesting and important discovery that a dense heavy deposit of lead may be obtained by the use of a solution of lead silico-fluoride, $PbSiF_6$, with the addition of a trace of gelatin. This discovery led to the development of what is known as the "Betts Process" for lead refining, which is in extensive commercial use.

Electrolytic Recovery of Metals. One of the alluring prospects which has been held out in connection with electrochemistry is its application to the recovery of metals from the ores. It has been thought by many inventors that the electrolytic methods might compete with the smelting and wet extraction methods constituting general metallurgical practice, but more especially have inventors been directing their attention to the recovery of values from refractory or non-workable ores discarded in current metallurgical practice.

Gold from Sea Water. It has been known for a long time that sea water contains gold in such quantity that a cubic mile of the sea water taken at almost any locality contains a great wealth of this precious metal. It is also known that gold can be deposited from an aqueous solution by the passage of an electric current, and this fact has led to many attempts at the electrolytic recovery of gold from sea water. These attempts have all been failures through neglect to recognize certain fundamental laws of electrolysis. The gold which is in solution is probably present as gold chloride, but in exceedingly dilute solution. If this electrolyte is placed in an electrolytic cell, the gold will migrate very slowly toward the cathode.

The sea water contains chlorides of sodium and magnesium as well as various other dissolved substances and these also act as an electrolytic conductor carrying the current. In passing current then through such a cell, most of the current is consumed in decomposing the more abundant materials to the exclusion of the gold. In figuring the cost of electrical energy, the corrosion of the anode material, and the interest and depreciation of the investment tied up in the cell construction, there is no possibility of a sufficient gold recovery to repay even an exceedingly small fraction of the necessary expense.

Other Metals. Various complex ores of zinc containing lead and silver and certain other elements have resisted treatment by metallurgical methods and have constituted an attractive material for electrochemical work. Many other examples may be named, but as yet no notable commercial success has been achieved in the electrolysis of aqueous solutions for the extraction of metals from their ores. As to the electrolysis of fused electrolytes, the conditions are different, as evidenced by the aluminum industry to be described later.

General Features of a Recovery Process. To treat an ore or a waste product containing a metal necessitates, first, getting it into an aqueous solution. This may be done by treatment with an acid and then dissolving out the soluble compound. The next step is to treat these compounds in an electrolytic cell, depositing the metal upon the cathode from which it can be recovered. While the cost of leaching and extraction usually makes the process prohibitive, there are serious electrochemical difficulties, the chief of which is the difficulty of getting an insoluble and sufficiently cheap anode material. If a soluble anode material be employed, the expense caused by its corrosion may likewise become prohibitive.

The cost of electric energy involved is another important item. If, for example, in the deposition of zinc an insoluble anode be employed, the electromotive force at the cell terminals would be at least 3 volts. One pound of zinc, for example, weighing 456 grams would require 456 divided by 1.219, or about 374 ampere hours. At a pressure of 3 volts this makes a consumption of 3×374, or 1122 watt hours per pound of zinc. The cost of this energy would thus constitute a serious item of expense.

ELECTROPLATING

The most widely extended use of the electrolytic cell is in the art of electroplating. This is the art of coating a surface with a thin layer of dense adherent metal. Gold and silver are used mainly on account of the ornamental properties of these metals, while zinc is employed mainly on account of its protective action. Nickel has both ornamental and protective properties, and in fact each one of the metals capable of deposition has certain properties which give it some value in the electroplating art.

By Simple Immersion. As differing from the art of electrodeposition, we have what is known as the coating by simple immersion, whereby one metal may receive a deposit of another metal by simply dipping it into a solution containing some of the latter metal. For example, in dipping a piece of clean iron into a copper sulphate solution, a coating of copper is quickly produced. Copper when dipped into certain silver solutions, likewise attains a silver coating; and coatings of gold are applied to brass by this same method in the manufacture of cheap jewelry.

Coatings obtained by simple immersion are of little practical importance, however, due to the fact that the coatings at best are either exceedingly thin or are laid down in a porous and non-adherent condition. It is practically impossible to secure an adherent durable coating of copper on iron by this method. In fact, it is a general purpose of the electroplater to avoid solutions which will produce deposits by simple immersion without the aid of the electric current.

PRINCIPLES OF ELECTROPLATING PROCESS

Electroplating Cell. The electroplating cell consists usually of a tank or containing vessel for holding a suitable solution of the metal to be deposited. Metal bars from which the anodes are suspended are placed above the tank. These are connected to the positive lead of the dynamo or other source of current, while the bars from which the cathodes are suspended are connected to the negative lead from the dynamo.

It is customary to place an adjustable resistance or rheostat in series with each tank, so that the amount of current flowing through the tank can be adjusted in accordance with the amount of cathode surface. It is highly desirable, though by no means common practice, also to include an ammeter in series with each tank for measuring the current flow.

Current Supply. The current supply for plating may be derived from primary batteries, from storage batteries, or from a low voltage dynamo. The earlier art of electroplating was dependent almost entirely upon primary batteries, but the greatest advance in the art came with the introduction of the electric dynamo, whereby the cost of electrical energy was enormously reduced. For small scale and experimental work, a battery source may be most convenient; but for technical work, one of the highly efficient types of plating dynamos must be employed.

The voltage at which the dynamo must run is from three volts to six volts and sometimes even higher, dependent upon the general nature of the work to be done.

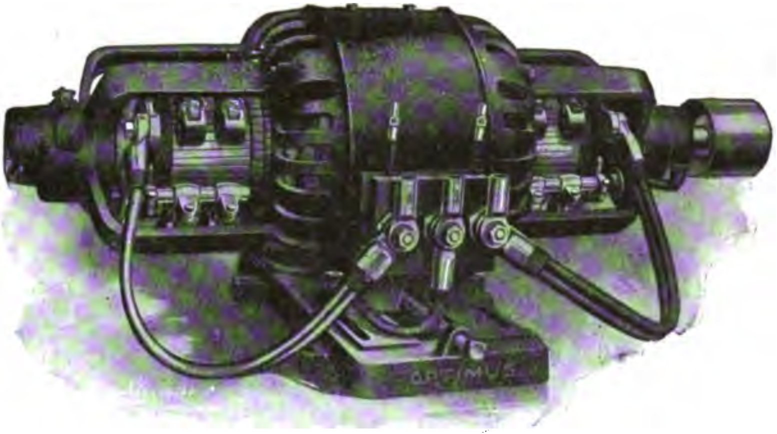


Fig. 2. Plating Dynamo with Double Commutator
Courtesy of Munning-Loeb Company

The low voltage plating dynamo is in general similar to the direct-current dynamo used for lighting and power purposes and differs in detail mainly in having a very large brush and commutator surface for carrying away, with as little heat as is possible, the large volume of current which is generated.

To give a large commutator and brush bearing surface, plating dynamos are frequently constructed with two commutators. Fig. 2 illustrates a modern type of plating dynamo. The leads running from the dynamo to the various tanks are usually of a very heavy copper wire or bar suitable for carrying a large volume of current without heating and to produce a minimum drop in voltage.

Fig. 3 shows the method of connecting a number of plating tanks fed from one dynamo.

Anodes. The anodes which are usually employed are of the soluble type and consist of the metal which it is desired to plate. In some rare cases an insoluble anode may be employed but this always involves a progressive change in the composition of the solution and interferes with simplicity of operation.

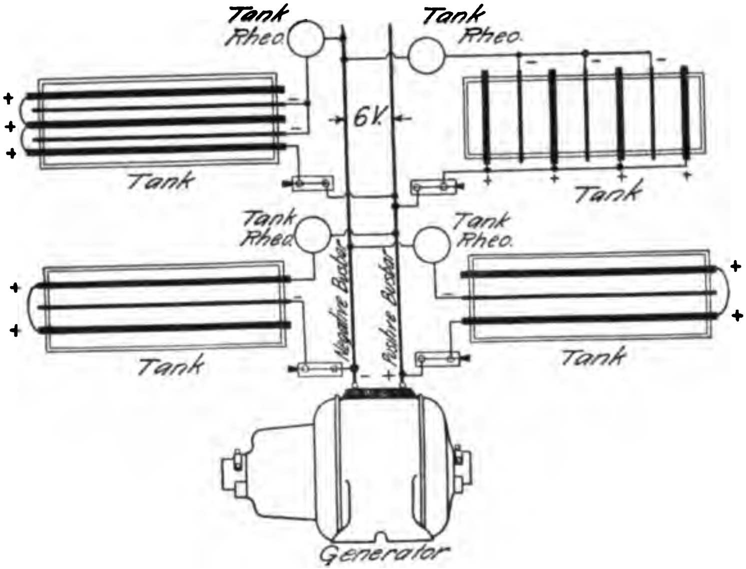


Fig. 3. Wiring Diagram for Tank Connections with Two-Wire Generator
Courtesy of Munning-Loeb Company

Factors in Successful Operation. *In General.* As to the general methods of operation, the electroplating process is simple, the metal being laid down by the action of the electric current, the thickness being dependent upon the amount of current and the length of time that the current flows. The process of electroplating is, however, beset with innumerable difficulties which the plater must know how to avoid. Much of the necessary information may be found in the various textbooks, but the successful practical plater is dependent largely upon the knowledge gained through extensive experience.

Quality of Deposit. The success of electroplating depends primarily upon the physical quality of the metal deposited. While in electrolytic refining coherence and density are not of greatest importance, density, coherence, and adherence are absolutely essential for protective and ornamental coatings. In general, there is a tendency for electrodeposits to become rough, especially after attaining some thickness. It is possible to secure metal deposits which are fern-like or tree-like or, in fact, imitative of almost all forms of vegetation, and to suppress these undesirable forms and to secure a dense smooth deposit constitutes much of the work of the electroplater. He finds he can regulate the quality of the deposit by various methods, such as the density of the solution, the composition of the solution, the current density, the temperature, the impurities, and various other factors.

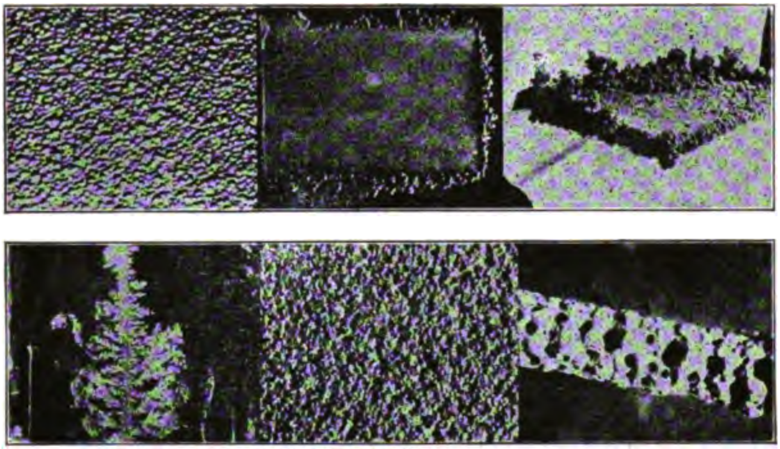


Fig. 4. Some Undesirable Forms of Electrolytic Deposits. Reading from Left to Right, Top: Nickel, Copper, and Iron. Bottom: Gas Bubbles in Heavy Nickel Deposit, Antimony, and Zinc

Courtesy of Metal Industry

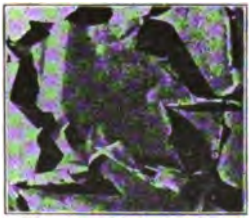


Fig. 5. Curling of Nickel Deposit

Courtesy of Metal Industry

Figs. 4 and 5 illustrate some of the forms which deposited metals may assume unless suitable precautions are observed.

Each metal has inherent qualities or tendencies as regards deposition. For example, nickel and iron tend to deposit in a finegrained dense state; copper is markedly crystalline; lead, tin, and silver tend to come down in a loose spongy or leaf-like formation; while platinum almost always deposits as an amorphous powder. It has taken about a century to develop the electroplating art to its present state in which practical working solutions are found for almost all of the metals. There is abundant opportunity, however, for further discovery of new electrolytes to overcome some of the present difficulties.

Addition Agents. A notable recent progressive step consists in the use of glucose or gelatin, or certain other inorganic materials, which, added to the ordinary plating solution, produce profound changes in the quality of the deposit.

Polishing. It is invariably desired that the resultant surface shall be smooth and polished. To secure the polish it is almost always necessary to subject the article to a buffing or burnishing operation. By the use of plating baskets and by the use of certain solutions, however, bright nickel and other deposits may now be secured.

The electroplater must know not only how to make up his original solutions from commercial materials, but even more important is his knowledge of how to maintain his solutions in constant working condition. If the anode metal does not go into solution in an amount exactly equal to that plated out at the cathode, the electrolyte will become depleted in metal and this must be supplied by dissolving up suitable materials. Careful attention is necessary to maintain a certain degree of acidity or alkalinity, as the case may be.

Influence of Current Density. The factor which the plater has chiefly under his control is the current density. It is usually desired that the metal shall be deposited as rapidly as possible, so that the output of a given tank shall be a maximum. There is a limit, however, beyond which the amount of current cannot be increased, and that is determined by the influence of the current density upon the quality of the deposit.

Each metal plating solution has a certain current density, usually expressed in number of amperes per square foot of cathode surface, beyond which the current cannot go. In nickel plating this is usually from five to ten amperes per square foot. In copper plating with a sulphate solution the current density may go far beyond this figure. In general, a current density under ten amperes per square foot is employed.

If the safe current density is exceeded, it produces a discolored deposit usually termed a *burned deposit*, this term being employed on account of the resemblance of the coating to an actual heating effect.

Adherence. The adherence of a metal deposit depends on characteristics of the metals involved as well as upon the care in doing the work. If a metal having a high coefficient of expansion is deposited upon one having a low coefficient, there will be a subsequent tendency for the coating to flake or peel off. This is a factor which is, of course, beyond the control of the plater; but a much more important factor which is entirely within his control is the method of preparing the surface which is to receive the plating. If this is properly done, the deposited metal may actually alloy with the metal to be coated; while if it is not properly done, the adherence will be less perfect.

The primary requisite for a metal to receive a deposit is cleanliness. Not only must the surface be freed from ordinary dirt, grease, rust, paint, or the like, but it must be chemically free from oxides or other tarnishing films, some of which are so thin as to be invisible. If a cleaned article is brought into contact with the hands, a contamination of the surface may be produced which will make a subsequent coating non-adherent. This illustrates the extreme care which must be employed. Oils and grease are removed by the use of a hot alkaline solution. Acid solutions and pickles are employed for the removal of oxides. Each metal has its own particular acid pickle which yields the characteristic and best results, but these details need not be considered here.

Principal Items of Expense. Grinding and polishing constitute the most costly part of the electroplating industry. It is a purely mechanical operation, by which abrasives or polishing materials are used either to remove adhering impurities from a surface or to give a surface the necessary smoothness. It is almost invariably true that during electroplating the surface becomes rougher instead of smoother and irregularities become accentuated rather than covered up. For this reason if a resultant smooth surface is desired, as smooth a surface as possible should be started with. Grinding and polishing before plating are, therefore, fully as important as the polishing and burnishing after plating.

The most important items of expense incident to electroplating are labor and materials. Labor is used mostly in the mechanical operations in preparing the surfaces or finishing the surfaces and in suspending the work in the tanks as well as in removing and rinsing. Where very small articles are to be handled, the labor and expense of stringing on wires would be prohibitive and for this reason there have been developed what are known as plating barrels or drums, by which a receptacle full of the small articles is rotated in a plating solution and the electrodeposit is formed while the articles are in a tumbling motion.

Fig. 6 illustrates a modern type of rotary plater in which nails or other small articles are plated without necessitating the stringing operation where each piece is handled separately.

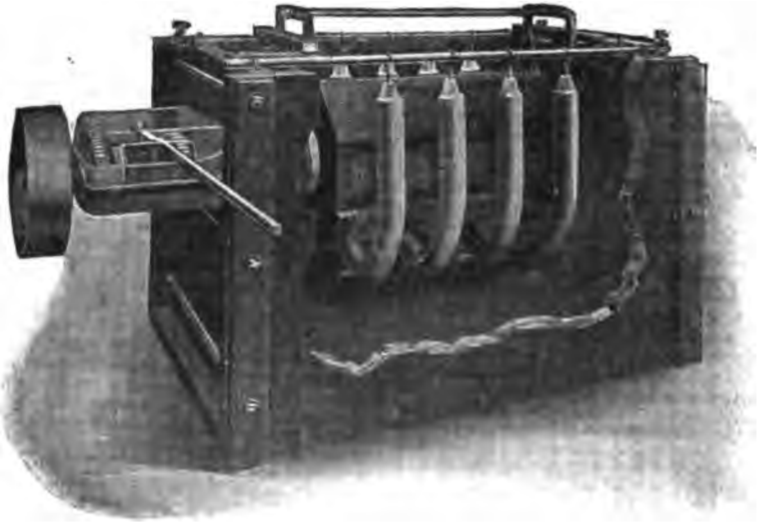


Fig. 6. Modern Rotary Plating Machine
Courtesy of Hanson and Van Winkle Company

WORKING SOLUTIONS FOR PRINCIPAL METALS

The following paragraphs give the essential details and satisfactory working solution for the deposition of each of the more important metals.

Copper. Copper is among the metals which are most easily deposited. A large number of different solutions are employed, but the action of the two typical ones will be described.

(1) *Acid Copper Solution.* The so-called acid copper bath may be made up according to the following formula:

Copper sulphate crystals (blue stone) ($CuSO_4+5H_2O$)	2 pounds
Sulphuric acid (H_2SO_4)	½ to 1 pound
Water	1 gallon

Copper anodes are used with this solution, and the electrolyte being highly conductive and the anode metal going into solution readily, a low voltage is required, usually somewhere between one and two volts. This depends upon the current density employed and upon whether the anodes and cathodes are far apart or close together.

The current density is usually from 10 to 20 amperes per square foot of cathode surface where the electrolyte is kept quiet. By rapidly circulating the electrolyte, however, much higher current densities may be employed while obtaining satisfactory deposits. With rapid circulation, current densities as high as 100 amperes and over may be employed.

This acid copper bath is used mainly for electrotyping and the deposition of copper in thick coatings. It cannot be employed satisfactorily for depositing directly on iron, because of the fact that iron throws the copper out by simple immersion and produces a loosely adhering deposit. When it is desired to copperplate on iron, the iron must be first given a preliminary coating from the so-called alkaline bath or the cyanide solution.

(2) *Alkaline Copper Solution.* Potassium cyanide is an exceedingly important chemical compound for electroplating use. It has the property of dissolving in water and then dissolving up various metal compounds, such as copper, gold, and silver, to produce excellent electrodeposits. The chief objection to its use is its deadly poisonous nature.

For preparing a cyanide copper bath, about 1½ pounds of potassium cyanide is dissolved in a gallon of water. Three-fourths of this solution is warmed up and in it is dissolved copper carbonate to the saturation point. About 12 ounces of the carbonate will thus dissolve. After pouring off the clear liquor, the remaining one-fourth of the original cyanide solution is added and the electrolyte is ready for use.

Copper anodes are employed and an electromotive force of from 3 to 5 volts is necessary to get the results. A current density of from 20 to 30 amperes per square foot may be used, although in operating under these conditions the amount of copper deposited is much less than is indicated by Faraday's law.

Nickel. The nickel bath in most general use is a saturated solution of the so-called double nickel salts. This consists of nickel ammonium sulphate $[(NH_4)_2.SO_4NiSO_4+6H_2O]$, twelve ounces of which will dissolve in one gallon of water. Nickel anodes, usually in the form of an impure cast nickel, are employed.

Some recent changes including the use of chlorides have resulted in improvements, but the old standard solution is in almost universal use.

In starting a batch of work, it is customary to employ a voltage of from 2 to 6 volts for a few minutes and then reduce to 2 or 3 volts, or even less. A current density of less than 10 amperes is all that can be economically employed. Too high a current density results in a black or burned deposit of nickel.

The above are simply illustrations of electroplating baths and are typical of those used for the deposition of zinc, silver, gold, etc.

PLATING NON-CONDUCTING BODIES

An interesting branch of the electroplating art has developed recently and has attracted marked attention on account of the novelty and beauty of the work which is being done. Fig. 7 shows how silver has been deposited upon glass and illustrates one of the numerous applications of a metal coating to a non-conductive material. Lace and other fabrics are being metallized; small animals, insects, flowers, leaves, and the like, can be coated electrolytically and thus be perpetuated in form and given the beauty of color through the range of those colors that lie under the control of the electroplater.

Rendering Surface Conductive. An essential step in the deposition of metals on non-conductive materials is first to render the surface conductive. This can be done in numerous ways; the best known being that illustrated by the practice of the electrotyper who takes a wax impression or mold from a form of type or metal design to be duplicated. This wax form is carefully dusted and brushed with a layer of high-grade conductive graphite, which, when applied to the mold, makes it appear like stove polish. This is the conductive surface which must constitute the starting point for the shell of copper which is subsequently to be deposited. For fabrics, flowers, leaves, or the like, the graphite will not adhere until first a layer of shellac or other sticky material is applied.

To avoid the use of graphite and the troublesome methods of applying, various chemical processes have been devised. A preliminary metal coating is obtained by dipping the article into a solution of a metal which is easily reducible. The wet surface is then treated with a reducing agent to throw out the metal, after which the plating can proceed by the ordinary chemical process. A solution of silver or platinum is suitable; phosphorus, pyrogallic acid, and various other reducing agents may be employed.

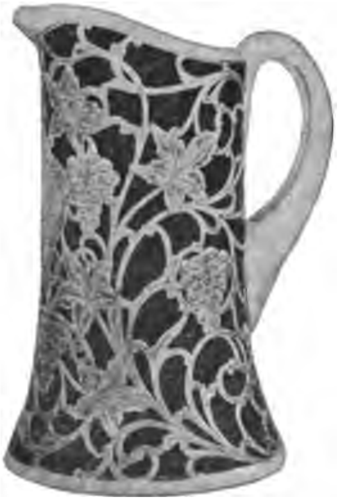


Fig. 7. Silver Deposit on Glass
Courtesy of Metal Industry

Plating on Glass. For plating on glass where the demand is for ornamental effect as well as a strongly adherent deposit, the glass may be rendered conductive by applying a metal paint, such as finely ground silver in turpentine, and then heating in a reducing atmosphere, under which conditions the silver will actually fuse to the glass. After cooling down, the glassware is wired in the ordinary way and put into the plating tank where the metal is deposited to the desired thickness.

DECOMPOSITION OF SALT SOLUTIONS

SODIUM CHLORIDE

Salt, NaCl, is a low priced and abundant material, which upon electrolytic decomposition may produce a number of valuable products for which there is a ready market. The apparent profits have attracted numberless inventors and, out of a large number of cells and processes which have been patented, a few have attained notable industrial success.

Decomposition of Solution. As explained on pages 41 to 44, the simplest and most direct way of decomposing salt is by the fusion process, electrolysis yielding sodium and chlorine. But the great difficulties have confined most of the electrolytic work to the decomposition of aqueous solutions of salt.

Illustrative Experiment. A simple experiment, easily performed, will illustrate one practical application of sodium chloride electrolysis. A solution of salt in water, about five to ten parts to one hundred of water, is placed in a glass or other non-conducting vessel, Fig. 8. Two graphite electrodes are inserted and a direct current is caused to flow for an hour, at a current density of from ten to twenty amperes per square foot of anode surface. After the solution has then been electrolyzed, it has remarkable disinfecting and bleaching properties. A piece of colored cloth may be whitened, and one quart of the solution may sterilize a hundred thousand quarts of contaminated drinking water. Offensive odors may be quickly destroyed by the remarkable oxidizing power of this liquid.

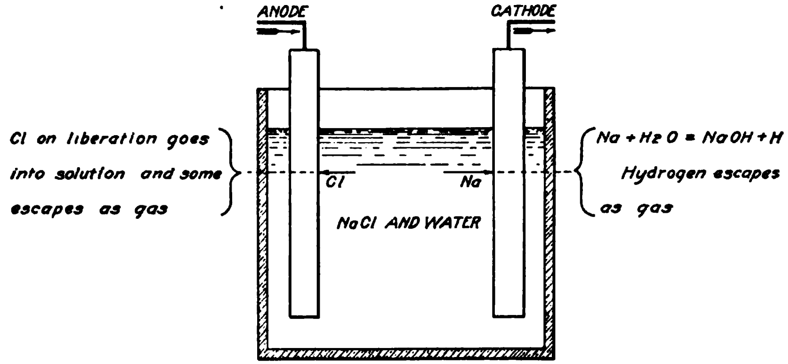


Fig. 8. Section of Electrolytic Cell Showing Decomposition of Sodium Chloride

As a result of these properties, this electrolytic cell has a field of usefulness in laundries; in textile mills; for purification of city water supplies; for disinfecting public swimming tanks; for treatment of sewage, for hospital use, and for many other purposes. A notable achievement has been the purification of an island in New York harbor which had been for years a dumping place for garbage, and which had become a public nuisance from the odors evolved. The purification was effected by electrolyzing sea water in wood tubs, using platinum anodes, and then pumping this solution on the land.

On account of the simplicity and effectiveness of the process, much attention has been drawn to it, and it naturally follows that extravagant and unwarranted claims have been made for it.

The oxidizing power of the electrolyzed salt solution is dependent upon the presence of sodium hypochlorite, $NaOCl$. This is similar in composition and chemical action to so-called chloride of lime or bleaching powder, which is calcium hypochlorite, $Ca(OCl)_2$.

Action in Cell. A study of the chemical changes which take place in this type of electrolytic cell, shows how sodium hypochlorite and various other substances may be produced.

$$Na+H_2O=NaOH+H \quad (1)$$

$$2NaOH+2Cl=NaOCl+NaCl+H_2O \quad (2)$$

or

$$6NaOH+6Cl=NaClO_3+5NaCl+3H_2O \quad (3)$$

While there are numerous reactions which take place, the simplest and most important are those set forth in equations (1), (2), and (3).

The primary action of the electric current is to draw the chlorine ions toward the anode, and the sodium ions toward the cathode where they are liberated in an amount to agree with Faraday's law. The sodium cannot exist in the free state in contact with water, hence the reaction (1) takes place by which hydrogen is liberated as a gas, and a solution of sodium hydrate or caustic soda is formed. This is very soluble and diffuses throughout the electrolyte.

The chlorine which is liberated at the anode is soluble to some extent in the electrolyte, and it is only when liberated rapidly that some of it escapes as a gas into the atmosphere. There is, however, a strong affinity between chloride and sodium hydrate, and a chemical action shown by equation (2) takes place; that is, some sodium hypochlorite, $NaOCl$, is formed, together with an equivalent amount of salt and water.

If there is an excess of sodium hydrate, and the temperature is raised, the reaction becomes that shown in equation (3) where sodium chlorate, $NaClO_3$, is formed, together with salt and water.

The conditions can be regulated so as to favor either one of the reactions. That is, either hypochlorite or chlorate can be produced at the will of the operator, by variation of temperature, density of solution, and duration of electrolysis. Both of these materials have strong oxidizing power and both have important technical applications.

It is evident that the decomposition of potassium chloride, KCl, may be effected in the same manner as the sodium chloride, and by its decomposition practically all of the potassium chlorate of commerce is now produced. This is a material used extensively in the manufacture of matches, explosives, and for other purposes where a strong oxidizing agent is needed.

MANUFACTURE OF HYPOCHLORITES

Chemical Action. As indicated above, the production of sodium hypochlorite takes place in accordance with the equation

$$2NaOH+2Cl=NaOCl+NaCl+H_2O$$

As the process continues there is a steadily increasing amount of sodium hypochlorite in the solution and, like the salt, it may in turn be decomposed by the current. When this occurs oxygen is liberated at the anode. Therefore it is possible to attain only a certain strength of solution before the hypochlorite is decomposed as rapidly as formed, and for the sake of economy of energy the concentration of hypochlorite is not usually carried much beyond ten grams of active chlorine per liter of solution. In using this solution for bleaching and disinfecting purposes there is a considerable consumption of undecomposed salt which is necessarily lost, and which adds to the cost of the process unless a very cheap source of salt, such as sea water, is employed. The important items of cost in sodium hypochlorite production are the following: salt, which is decomposed together with that which accompanies the hypochlorite solution; electrical energy; and anode renewal. Since oxygen is liberated at the anode, and since carbon and graphite corrode under such conditions, the anode loss may be considerable. The cost of electrolytic hypochlorite is usually greater than that at which an equivalent amount of bleaching powder can be purchased. Nevertheless on account of convenience, cleanliness, and greater effectiveness of sodium hypochlorite over calcium hypochlorite, this type of cell has extensive use.

Commercial Electrolyzers. Among the types of commercial electrolyzers for hypochlorite is the one illustrated in Fig. 9. This shows a supply tank for dilute salt solution, feeding in a steady stream into the stoneware trough or electrolyzer. The overflow from this tank carries the hypochlorite solution into the larger rectangular storage tank below.

Since a pressure of about 5 volts is all that is needed between the anode and cathode, if current be taken from an ordinary lighting or power circuit, usually carrying a pressure of 110 volts, a rheostat to reduce the pressure at the cell terminals to 5 volts will be necessary. Since this is exceedingly wasteful of electric energy, it is avoided by placing a suitable number of cells in series so that little or no rheostat regulation is necessary. This is accomplished in the apparatus illustrated by placing a number of partitions of graphite plates spaced evenly along the trough and separated by insulating cleats. The end plates are connected to the high voltage source of current.

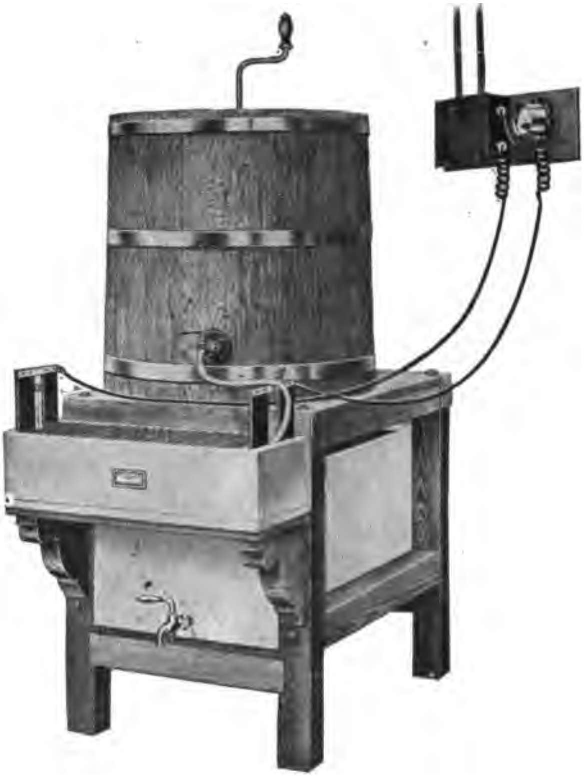


Fig. 9. Chlorinator, or Electrolyzer, for The Decomposition of Salt
Courtesy of the Valhalla Company

This construction is illustrated diagrammatically in Fig. 10. Fourteen compartments are shown, divided by graphite plates. Each compartment acts as an electrolytic cell, the electric current flowing in at the left end plate, and the left-hand side of the next plate acts as the corresponding cathode. The right-hand side of this same plate serves as the anode for the next compartment, and so on. This construction serves as a simple method of connecting cells in series without using a containing vessel for each pair of electrodes.

The salt solution flows downward between plates *1* and *2*, under plate *2* which is spaced a short distance from the bottom, upward between plates *2* and *3*, over plate *3* and then downward, and so on through the electrolyzer. The rate of flow of the solution is adjusted so that by the time it has passed through the last compartment it has been electrolyzed to the desired strength.

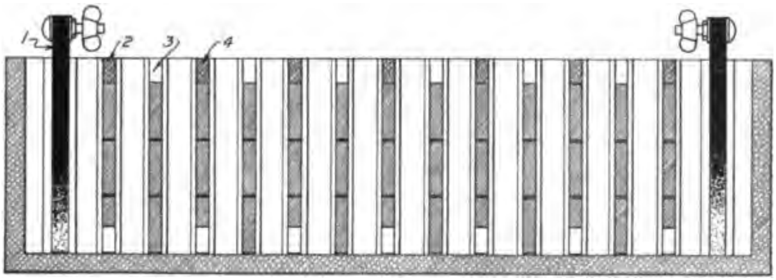


Fig. 10. Section of an Electrolyzer for Salt Solutions

MANUFACTURE OF CHLORINE AND CAUSTIC SODA

A process of far greater industrial importance than the production of sodium hypochlorite is the electrolytic decomposition of salt solutions for the manufacture of chlorine and caustic soda. The chlorine which is liberated is absorbed by lime in the manufacture of bleaching powder, or it may be taken up by lime solution to form a hypochlorite bleach liquor.

Practically all of the bleaching powder now on the market is an electrochemical product. Paper mills and other larger users of bleaching powder have installed, or are installing, electrochemical plants for this purpose. Caustic soda, which may be considered a by-product of this industry, is in great commercial demand and electrolytic caustic has largely replaced the products of the old methods.

Difficulties. In order that the electrolytic cell may deliver chlorine and caustic, it is evident that the construction and operation must be such as to prevent these materials coming together within the cell. Otherwise there would be formed sodium hypochlorite, which is decidedly detrimental; in fact the most effective test of the value of the electrolytic cell is the freedom from hypochlorite within the cell.

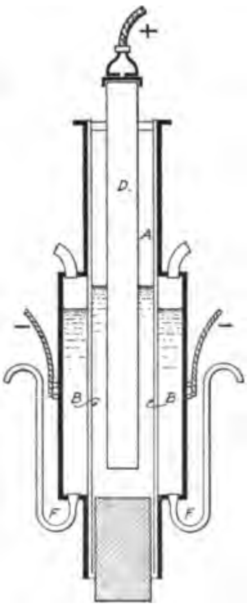


Fig. 11. Townsend Diaphragm Cell

Since the cathode product is extremely soluble in the electrolyte and the chlorine liberated at the anode also has considerable solubility, the problem of keeping these products separate is more difficult than is the separation of oxygen and hydrogen in the electrolytic decomposition of water. Several successful methods of effecting this have been devised, the principal ones being the use of some kind of a *diaphragm,* and the use of *mercury* as the cathode material.

Methods. *Diaphragm Cells.* As illustrating one of the several types of successful diaphragm cells, the Townsend cell may be referred to. This is employed in a large plant located at Niagara Falls.

The cell construction is shown diagrammatically in Fig. 11. The central compartment *A* contains the graphite anodes *D*. The anode channel is made up of a U-shaped framework of cement construction, the sides being closed by a sheet asbestos diaphragm *B* of special construction. On the outside of the diaphragm *B*, perforated iron girds are bolted tightly to the framework. On the outside of the cathode sheets are channels for the collection of the caustic soda. The particularly novel feature of this cell is that the two outer channels are filled with kerosene oil. The caustic soda solution which is formed at the cathode trickles through the diaphragm and sinks through this layer of oil and is drawn off through outlets *F*. This oil together with the diaphragm is intended to secure the complete removal of the caustic from the anode liquor. The brine solution to be decomposed is introduced into the anode chamber and the rate at which the solution flows through the oil is determined by the height of the liquid in this compartment with respect to the height of the oil column in the outer compartments.

The removal of the alkali is so effective that very high current densities can be used and still maintain high current efficiency. These cells can be constructed to use 2500 amperes each. The operation of the cell shows a current efficiency of from 90 to 95 per cent, operating at a pressure of from 4½ to 5 volts per cell. The caustic which is drawn off from the cathode channels is a 15 per cent solution with an equal amount of undecomposed salt. The distinguishing feature and greatest limitation of all types of diaphragm cells are that the cathode solution which is drawn off consists of a mixture of both salt and caustic. A separation of these materials is necessary to put the caustic into a marketable condition and to prevent unnecessary waste of salt. This is accomplished by evaporation, the salt crystallizing out as the solution is concentrated.

Mercury Cells. Mercury has a remarkable property when used as the cathode in a salt solution, which is of great interest from a scientific standpoint and of great value from an industrial standpoint. When sodium is liberated on most cathode surfaces, it immediately unites with the water of an electrolyte to form caustic soda and liberate hydrogen. If, however, the cathode is mercury, the mercury absorbs the sodium before it has time to react with the electrolyte. It takes it in the form of an alloy or amalgam up to several per cent of its own weight. The completeness with which the sodium is taken up by the mercury depends somewhat upon the temperature, but more especially upon the purity of the mercury.

If this lead mercury amalgam be removed from the cell and placed in another compartment, it may be made to give up its sodium by using the amalgam as the anode. The sodium then goes into solution and forms sodium hydrate and liberates hydrogen upon the cathode. A simple method for making the amalgam act as an anode is to bring in metallic contact with it an electronegative material such as carbon or graphite.

The Castner cell is one of the oldest and most successful of the mercury type. Its construction is shown diagrammatically in Fig. 12, where it is indicated that the cell is divided into three compartments by two vertical partitions extending almost to the bottom of the cell, but not making a tight joint therewith. *A* and *C* constitute the anode compartments in which graphite anodes are employed. A layer of mercury rests on the bottom of the cell, making a seal beneath the two vertical partitions. The current is conducted away from the cell through the iron cathode in channel *B*. The current to flow through the cell must pass from the anode through the brine solution, thence to the mercury, and from the mercury through the caustic solution in compartment *B*, then to the iron cathode, and thence from the cell. The sodium mercury amalgam is formed in the anode compartments and this amalgam is transferred to the central compartment by a slow rocking motion which is given to the cell. The amalgam, therefore, surges back and forth, and while passing through the central compartment acts as anodic surface.

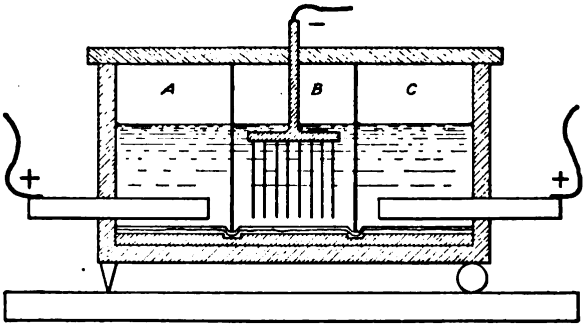


Fig. 12. Castner Mercury Cell

The actual operation of this cell introduces various complications which need not be described here, but the cell has been very successful from a commercial standpoint in producing chlorine and caustic soda of high purity. An obvious limitation on the construction is the necessity of rocking the entire cell and this feature has been avoided in the construction of another successful type of mercury cell known as the Whiting cell.

The cell body is a stationary, massive construction of concrete in which the mercury rests in thin layers in the anode compartments.

There are a number of divisions to the anode compartments and the mercury from each of these devices is discharged intermittently and in rotation into the oxidizing chamber where it comes in contact with graphite plates against which it gives up its sodium to the caustic soda solution. After the sodium has been extracted, the purified mercury is elevated by a stoneware wheel so that it flows back again into the anode compartments. The construction of this cell is illustrated in Fig. 13, and Fig. 14 shows a large sized working plant of this construction. A cell 6 feet square takes 1400 amperes at a voltage of about 4 volts. A pure caustic is produced and, on account of the high current efficiency,[1] there is little hypochlorite production and, therefore, small anode loss.

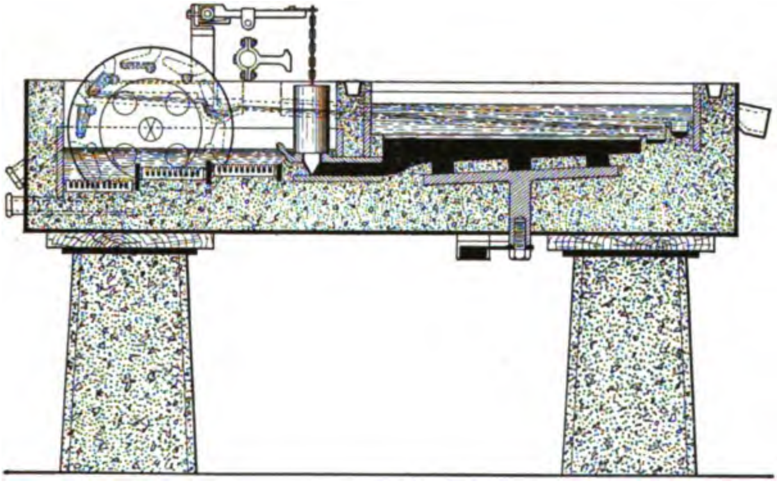


Fig. 13. Cross Section of Whiting's Electrolytic Cell

Relative Advantage of Mercury and Diaphragm Types. In view of the rapidly extending use of cells for decomposing salt, there is much discussion as to the relative merits of the mercury and diaphragm types of cells. The most important advantage of the former is its ability to produce a pure caustic soda solution, thus avoiding the expensive plant and costly operation of removing the salt from the caustic. On the other hand, the diaphragm process has the apparent advantage of cheaper cell construction, since the use of the costly mercury is avoided. Many other factors of lesser

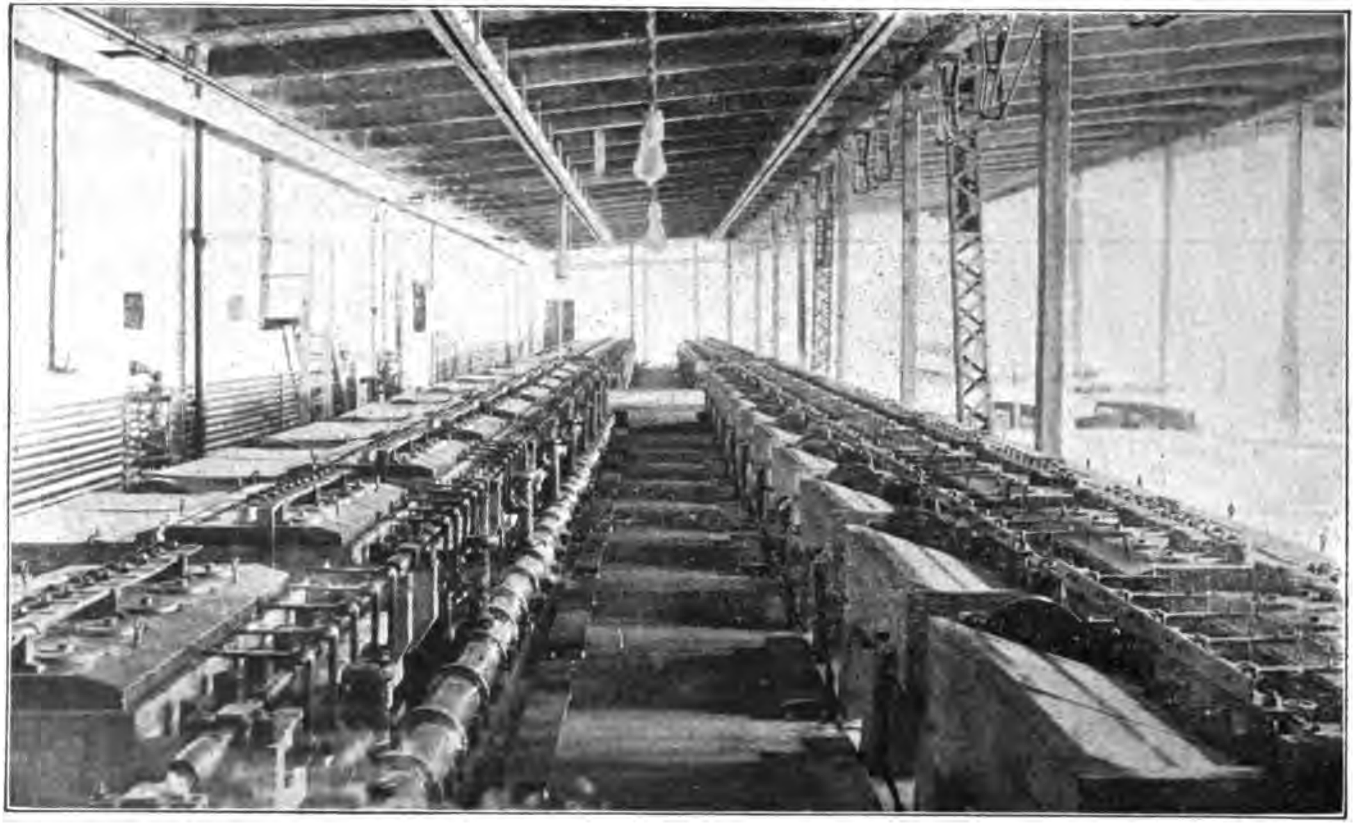


Fig. 14. An Installation of Whiting Cells in Operation

importance must be taken into account in considering the relative merits of the two types of cells, including the depreciation, anode renewal, cost of salt, cost of power, labor, etc. Whether or not one cell has the advantage of the other depends to some extent upon local conditions.

ELECTROLYTIC HYDROGEN AND OXYGEN

Uses of Hydrogen and Oxygen. Hydrogen and oxygen have extensive industrial applications. In addition to their many uses in chemical manufacture, these two gases are coming into extensive employment for oxy-hydrogen welding, and for other metallurgical operations. Oxygen is also used for similar purposes in connection with acetylene, and other hydrocarbon gases. Hydrogen is an excellent chemical reducing agent, and one of its large applications is for aeronautic use.

Hydrogen is given off at the cathode as a by-product in the decomposition of salt solutions and in various other electrolytic processes, and is usually regarded as a waste product. Oxygen is of greater value. It is produced to some extent by the liquefaction of air and its subsequent distillation. In this case it is mixed with a small amount of nitrogen but enough to prevent its most efficient use in attaining high temperatures in combustion operations. The pure gas can be made most economically by the electrolytic method, and the simultaneous production of both oxygen and hydrogen constitutes a profitable electrolytic industry.

Cells for Decomposing Water. Electrolytic cells of various types have been developed. They all employ either a sulphuric acid, or a sodium or potassium hydrate solution as electrolyte. Where the acid solution is used, lead is the material used in the cell construction; while with the alkaline electrolyte, iron is employed. This choice of materials is made because of the insolubility of lead and of iron in the respective solutions. It is obvious that insoluble anodes must be employed to allow the escape of oxygen.

Separation of Gases. An important point to be attained in water decomposition is that the anode and cathode products be kept as completely separated as possible. The bubbles of hydrogen coming off the cathode surface must not mingle with the oxygen bubbles from the neighboring anode surface. Otherwise impurity of products results and, what is of greater importance, a liability of explosion is produced. Numerous fatalities have resulted through inadequate precaution in this respect.

The electrodes must be placed as near together as practicable to reduce the resistance and the power consumption to an economical figure.

A 20 to 30 per cent sulphuric acid solution has a better conductivity than a 10 to 25 per cent alkali solution. On the other hand, it takes a somewhat higher electromotive force to liberate oxygen and hydrogen from the former solution, so that electrolyzers using the caustic soda or caustic potash have a slightly lower energy consumption than have those using the acid. The current efficiency approaches close to 100 per cent; that is, the oxygen and hydrogen are liberated in almost exact accord with Faraday's laws. This is essential to produce gases of the highest purity—about 99 per cent pure. Since the acid or alkaline is added to the electrolyte to give the conductivity to it and water alone is decomposed, it is necessary to add distilled water from time to time to replace that electrolyzed.

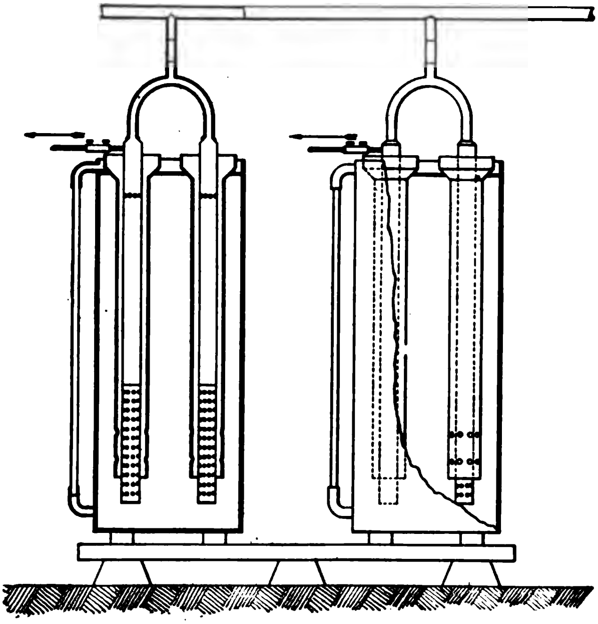
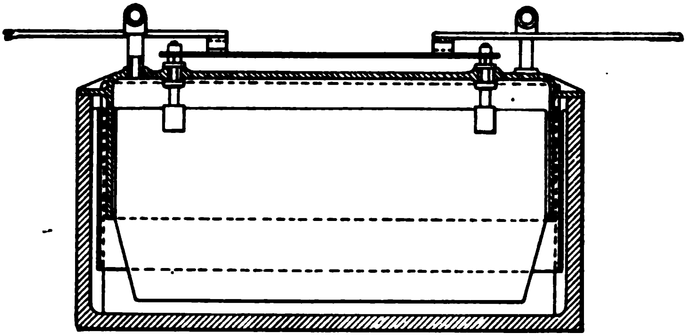


Fig. 15. Sections of Schoop Electrolyzer

Types of Cells. Among the various types of electrolyzers employed are the following:

Schoop. The Schoop system uses sulphuric acid and cylindrical lead-lined vats containing a number of vertical electrodes. These are in the form of long tubes filled with fine lead wire to increase the active electrode surface, each electrode being surrounded by a cylindrical tube of non-conductive material open below and perforated toward the bottom to allow the flow of current. The gas generated inside of this tube passes upward, where it is collected. This apparatus is illustrated in Fig. 15.



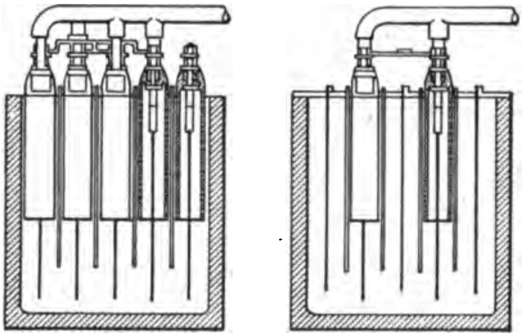


Fig. 16. Sections of Schuckert Electrolyzer

Schmidt. The Schmidt electrolyzer uses an alkaline electrolyte and the construction resembles a filter press. The electrodes are iron plates corrugated and are separated by diaphragms of asbestos with rubber packing around the edges. The purpose of this diaphragm is to keep separate the anode and cathode gases.

Schuckert. Another illustration of the alkaline type of cell is known as the Schuckert. In this an iron trough is divided into a number of compartments by vertical partitions of an insulating material extending from the top three-quarters of the way down the cell. These compartments contain alternately iron anodes and cathodes. Iron hoods suspended between the partitions carry off the gases. The construction of this cell is shown in Fig. 16.

A full sized plant equipped with International Oxygen Company cells is shown in operation in Fig. 17. For these cells a pressure of from 2½ to 3 volts and a current of 600 amperes is required.

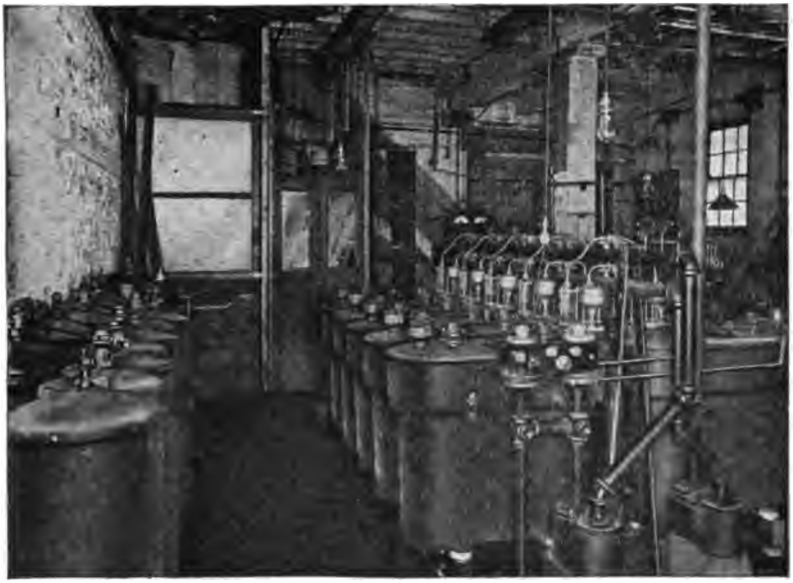


Fig. 17. Installation of an Oxygen-Hydrogen Plant
Courtesy of International Oxygen Company

Plant Equipment. An essential part of any electrolytic plant is a high pressure pump which is used to compress the gases into tanks for storage, although when the gases are to be used where manufactured, large tanks such as are used in gas works may be sufficient. Precautions against explosions must be carefully observed. In operating the compressor oil is not permissible for cylinder lubrication on account of the possibility of the oil getting into the oxygen and forming an explosive mixture. Glycerine is commonly employed for this purpose. Among other safeguards is the use of either an iron tube kept at a red heat or a tube filled with platinum sponge, or similar contact material. The gases from the electrolytic tanks will pass through such tubes, and whatever hydrogen there may be in the oxygen, or whatever oxygen there may be in the hydrogen, is consumed in producing water, and the purification is thus effected.

The gases when used for blow-torch purposes are passed through water-cooled funnels to prevent any possibility of the flame traveling backward into the tanks.

In view of the improvements being made and the high economy of the process, the electrolytic generation of oxygen and hydrogen promises to become an industry of great importance.

FUSED ELECTROLYTES

The majority of chemical compounds which are solid at ordinary temperatures become conductive when heated up to and beyond the melting points. The nature of this conductivity is usually electrolytic; that is, the molten materials are electrolytes which are capable of undergoing decomposition during the passage of a direct current. The conductivity of these materials is usually of about the same order as that of aqueous solutions.

The fact that we have molten electrolytes is of considerable technical importance, for upon it is based the recovery of various metals which would decompose water and, therefore, be unrecoverable by use of an aqueous solution. The aluminum industry is based upon the decomposition of a fused aluminum compound. The production of calcium, of sodium, and of magnesium is likewise dependent upon the decomposition of fused compounds of these respective metals.

MANUFACTURE OF SODIUM PRODUCTS

Fused Salt. The chemistry of the decomposition of melted salt is much simpler than is the chemistry of decomposition of aqueous solutions of salt. The electrolyte consists of only two elements: sodium and chlorine. Salt can be melted at a temperature of about 900° C. (a bright red heat). When placed in a suitable container and with an anode of carbon and graphite and a cathode of iron or other suitable metal, the sodium is liberated at the cathode and the chlorine at the anode. These two elements being liberated have nothing with which to react, as in the case of aqueous solutions, and they will thus be recovered in the free state.

The simplicity of this process is, however, apparent rather than real when considering the various practical difficulties which are encountered. These difficulties depend upon the high temperature, under which condition the sodium vaporizes and has to be cooled by some suitable method. Such suitable method, however, has not been worked out technically. The chlorine which comes off at the anode being very hot is correspondingly active and the collection and cooling of this material presents difficulties. Also the construction of a containing vessel which will resist the attack of fused salt as well as of the liberated sodium and chlorine, is not a simple matter, and the practical difficulties have defeated many attempts to carry out this process.

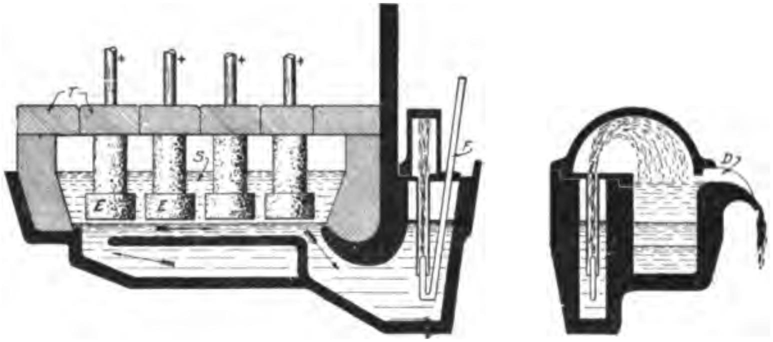


Fig. 18. Sections of Acker's Caustic Soda Furnace
Copied from The Electric Furnace, by Alfred Stansfield

Acker Process. Perhaps the most successful attempt has been the so-called Acker process, which was used for a number of years at Niagara Falls. In this process the fused NaCl was electrolyzed in a cast-iron cell of peculiar construction and lined with magnesia bricks. A cross section of this cell is illustrated in Fig. 18.

The cathode covering the bottom of the cell is fused lead above which rests a 6-inch layer of molten salt *S* and dipping into this are a number of graphite anodes *E* with terminals coming up through the tile roof of the cell *T*.

This process works upon the interesting principle that, when sodium is liberated upon molten lead, it alloys with the lead, forming an amalgam similar to the amalgams of sodium and mercury of the mercury process. To prevent the amalgam becoming too rich in sodium, the sodium is continually extracted from the molten metal by blowing steam through it by pipe *F*, as indicated in the right portion of the diagram. The steam on coming in contact decomposes the sodium to form sodium hydrate, NaOH, and liberates hydrogen. The molten caustic soda thus produced flows out of the cell through at *D*. The reaction between the steam and the amalgam is violent and causes a vigorous circulation of the molten lead.

The chlorine which is liberated in the anode is drawn off from the anode chamber under a slightly reduced pressure by means of a fan. This causes some inflow of air through the crevices in the cover and the gaseous products thus drawn off consist of one volume of chlorine to about ten times the volume of air, the chlorine being then extracted from this mixture by means of lime to form the commercial bleaching powder.

These cells took about 800 amperes at a voltage of about 7 volts, the current efficiency being about 93 per cent.

The anodes were found to have a high durability unless a considerable amount of impurity was in the salt; the presence of sulphates, for example, causes anode corrosion.

The caustic soda produced from this cell is in a fused condition, which on solidifying furnishes a marketable product without the necessity of evaporation involved by the aqueous electrolytic methods.

The high temperature difficulties and the difficulties of cell construction have apparently made it impossible for the fused electrolytic cell to compete commercially with the aqueous methods of sodium chloride decomposition, although future improvements may reverse this condition.

Metallic Sodium. In the manufacture of metallic sodium the electrolytic methods have replaced the older chemical methods and the success has been dependent upon the use of a fused electrolyte which melts at a point much lower than that of salt. The process in most general use is the Castner process, which employs molten caustic soda, NaOH. This is contained in an iron vessel, Fig. 19. In this apparatus there is an extension below the cell for the cathode rod *D* and it becomes sealed by the solidifying of some of the sodium hydrate at G. The cathode may consist of any one of several metals, iron being preferable. A cylindrical nickel anode C surrounds the cathode and between the electrodes is suspended a cylindrical screen of iron gauze. This prevents the sodium globules which are liberated on the cathode from floating over to the anode. The sodium which floats to the surface is ladled out periodically from F through the cover. For successful working, the temperature should be maintained by external heating as low as possible—not more than 20 per cent above the melting point of the material. The somewhat impure material commonly used has a melting point of about 300° C.

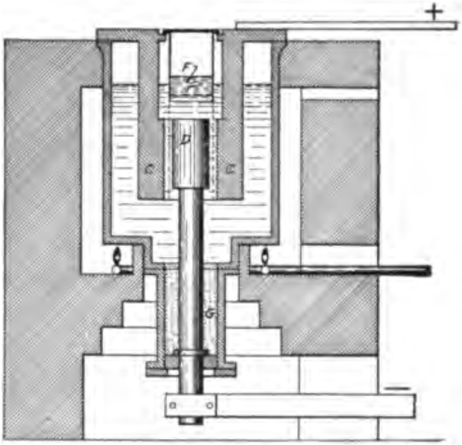


Fig. 19. Castner's Sodium Furnace
Copied from The Electric Furnace, by Alfred Stansfield

A single cell holds about 250 pounds of molten NaOH, takes a current of 1200 amperes at about 5 volts, and works at a current efficiency somewhat less than 50 per cent.

MANUFACTURE OF ALUMINUM

Aluminum is a metal which a half century ago was almost a chemical curiosity but which has now become one of the common and most useful metals in every day service. Although aluminum is one of the most abundant of the elements constituting the earth's crust, it has been locked up so tightly in combination with oxides, silicates, fluorides, and the like, that it has resisted until recently all efforts to isolate it in the metallic state. This has been finally accomplished in a practical way by electrolysis of fused aluminum compounds.

This element is found as an important constituent in most clays, but the known methods of extraction do not yet permit the use of such materials as an aluminum ore. Bauxite, which contains a high per cent of aluminum as hydrated oxide, is used almost exclusively in this industry, but to adapt it to the electric furnace requires, first, a chemical purification to remove such objectionable elements as iron, silicon, and titanium, after which process the material to be treated consists of a pure aluminum oxide, Al_2O_3.

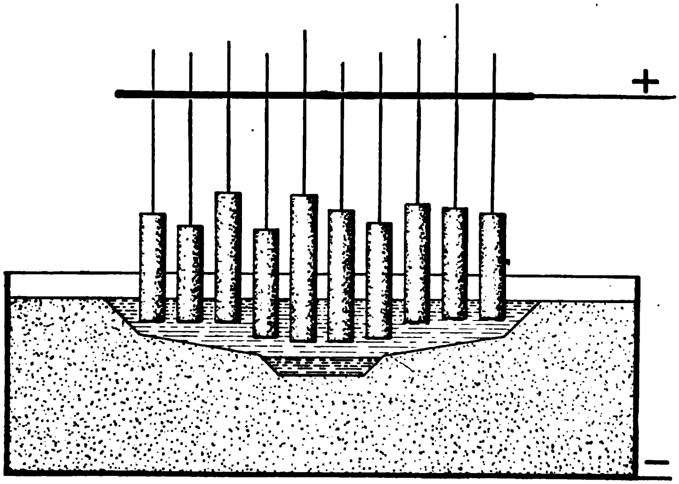


Fig. 20. Aluminum Furnace
Copied from The Electric Furnace, by Alfred Stansfield

The history of the aluminum process is interesting in that it records the almost simultaneous discovery of similar processes in America and in Europe. To Mr. Charles M. Hall is accorded the honor of working out the method commonly used in this country and by which the entire consumption of aluminum in America is supplied.

Hall Process. *Type of Cell.* The typical electrolytic cell, Fig. 20, may consist of an iron box about 6 feet long, 3 feet wide, and 3 feet deep, lined with a thick layer of conductive carbon. This layer prevents the fused material from coming in contact with an iron container and it also acts as the cathode terminal of the cell. The anode consists of a multiplicity of carbon rods 3 inches in diameter, suspended vertically in rows and numbering perhaps 40 to 50, *Solvent for Aluminum Oxide.* The important discovery upon which this process is based was in finding a suitable solvent for the aluminum oxide. Such solvent was molten cryolite, being a combination of sodium and aluminum fluorides, represented by formula $3NaF.AlF_3$. Calcium fluoride, CaF_2, is also added on account of its influence on the fusibility. This molten material readily dissolves a certain amount of the aluminum oxide, constituting a true electrolyte which undergoes decomposition upon the passage of the current.

A layer of charcoal is placed on top of the molten bath to protect it from oxidation, and the dry aluminum oxide is fed through this layer to replace that decomposed.

Action of Current. A cell, such as described, takes about 10,000 amperes of current at a pressure of 5.5 volts or upward, depending upon the condition of the bath.

In this cell the current serves a double purpose of heating the bath and keeping it in the proper molten condition for electrolytic decomposition. The aluminum is deposited on the carbon bottom constituting the cathode. At the working temperature the metal is molten and having a greater specific gravity than the electrolyte stays on the bottom. After it has accumulated to a suitable amount, it is tapped off.

At the carbon anodes a corresponding amount of oxygen is liberated and, at the temperature necessary for operation, this oxygen unites with the anode carbon to form carbon monoxide, a gas which on rising upwards burns in contact with the air to CO_2. The consumption of carbon may thus amount to from .5 to .7 of a pound, although on account of the action of the air on the heated carbon anodes and the scrap anodes which are produced, the consumption may run up to about one pound for each pound of material. The current efficiency is reported as being from 70 to 80 per cent. The energy consumption is stated to be about 23,000 kilowatt hours per ton of metal, or stated in other terms, one electrical horsepower a year will produce about one-quarter of a ton of aluminum.

Electrolyte. The electrolyte consists in the main of a number of compounds, chiefly sodium fluoride, aluminum fluoride, and aluminum oxide. It is a well-known fact in electrolysis that that compound in the electrolyte which has the lowest decomposition pressure will be the first one to be decomposed by the current. The following figures show why it is that the aluminum oxide undergoes decomposition rather than the sodium fluoride or the aluminum fluoride:

NaF —4.7 volts, decomposition pressure
AlF_3 —4.0 volts, decomposition pressure
Al_2O_3—2.8 volts, decomposition pressure

If during electrolysis there is an exhaustion of the aluminum oxide, the aluminum or the sodium fluorides may then be decomposed; this also happens to some extent if the current density is run too high.

The increasing demand for aluminum promises to make this industry of increasingly greater importance and this will be accentuated as the price is reduced. A scarcity of suitable ores is becoming felt and increased attention is being given to the extraction of kaolin and other cheaper and abundant materials.

ELECTRIC FURNACE

The use of electrical energy for the production of useful heat is becoming revolutionary not only in the field of metallurgy or technical chemistry where heat is utilized, but also in its effect upon the electric power industry. It is furnishing a load for power stations, or in other words a market for their product. Where heat from electrical energy is used for low temperature operations, such as cooking, drying, soldering, and the like, it is not generally classified as a branch of electrochemistry. When, however, high temperatures are attained, we pass into what is generally considered the field of electrochemistry. There is, however, no sharp line of demarcation as between low temperature and high temperature electric heating.

The device or structure used for transforming electrical into heat energy, where high temperatures are required, is called an electric furnace. The ability of the electric furnace to attain temperatures far beyond those hitherto available by other methods gave it a distinct field of usefulness in which it did not have to compete with existing furnaces. By the use of these temperatures many of nature's most closely guarded secrets have been revealed; a new chemistry of high temperatures has been evolved; new ideas as to the constitution of matter have been developed; new methods of preparing known substances have been formulated; our stores of available materials have been enriched by the discovery of new compounds.

Possibilities at High Temperatures. *All Substances Melt.* In the high temperature produced in the electric furnace it has been shown that all substances can be melted. The oft encountered statement that lime, magnesia, molybdenum, tungsten, and the like, are infusible is therefore incorrect, for not only can all known substances be melted, but they can be volatilized as well. These facts are full of significance and suggestion to the investigator. They show not only that there are limitations upon the materials which he may use for furnace construction, introducing difficulties where the highest temperatures are to be developed, but that it is possible that in the melting and fusion of materials they may undergo such transformation of their physical nature as to endow them with qualities of great value. One of the most successful industrial uses of the electric furnace is the fusion of aluminum oxide in the form of bauxite, resulting in the production of that physical form of the material designated by the trade name "alundum". This is a duplication of Nature's process for producing corundum, but the artificial product has marked advantages over the natural material in purity, cheapness, strength, and toughness, which give it greater value for abrasive purposes.

The fusion of quartz has produced a valuable material for a new kind of glassware which is indestructible by rapid or extreme variations of temperature. Various refractory materials have their refractory qualities increased by melting and subsequent cooling. Experimental investigation in this direction has only begun, but the results already obtained point to many improvements which may be made in materials for furnace construction, materials resistant to chemical corrosion, and materials possessing high heat and electrical insulating properties. The volatilization of elements and compounds at high temperatures gives new methods for the purification and separation of materials, enabling the process of fractional distillation to be applied to all substances.

Behavior of Carbon. It has been shown that carbon is capable of conversion into its various forms, a fact industrially utilized with great advantage by the International Acheson Graphite Company in making graphite and graphitized electrodes from the ordinary forms of coal and coke. Moissan has demonstrated the possibility of changing carbon into the diamond, and has reproduced, artificially, all the varieties of diamonds which Nature furnishes, alike in all respects save size.

All the oxides which had hitherto been regarded as irreducible have been reduced through the use of the electric furnace. Upon experiments which he has made, Borchers based the claim that carbon is capable of taking the oxygen from any known compound at temperatures within the range of the electric furnace. Similarly, other reducing agents may be made effective, and the decomposition can be produced even without any reducing agent whatever by utilizing the electrolytic action of the current. This has resulted in unlocking various of Nature's stores, making available for use such materials as aluminum, magnesium, calcium, sodium, potassium, chromium, silicon, and many others which previously could be obtained only with great difficulty if at all.

Carbides. Moissan's classic researches show us that a large number of elements unite with carbon to form carbides, many of which were not known before the day of the electric furnace. Based upon this fact, though resulting from the independent discovery of the American inventor, Willson, the calcium carbide industry has been developed, and today thousands of tons are being produced annually. The reaction of this carbide with water forms the hydrocarbon, acetylene, which, although now finding its chief use as an illuminant, is capable of being transformed into other hydrocarbons. Manganese carbide reacts with water to form hydrogen and methane; thorium carbide gives ethylene; and cerium and uranium carbides yield liquid and solid hydrocarbons as well as the gaseous ones. Although the hydrocarbons other than acetylene have not been produced commercially, scientifically it is possible to produce petroleum and other like compounds. Such discoveries as these point to the great and significant fact that the whole field of organic chemistry offers itself as an incentive in the exploitation of the electric furnace.

Another class of carbides, such as those of silicon, boron, chromium, molybdenum, tungsten, and titanium, are stable, not only resisting the attack of water but being extremely resistant to the most active chemical agents. The first of these, silicon carbide, or carborundum, has found extensive application as an abrasive, and its use has led to the development of a new industry. Its extreme hardness, approaching that of the diamond, and the refractory nature of it and similar carbides, together with properties which may yet be discovered, point to the probability as well as the possibility that other carbides will have quite as extensive industrial application.

Related Compounds. Moissan and his contemporaries have shown that silicon, boron, and nitrogen, may be made to act like carbon in producing silicides, borides, and nitrides, each new compound having its own peculiar properties, and that the field may also be extended through the manufacture of the more complex compounds, such as the silico-borides, silico-carbides, boro-carbides, etc.

A contemplation of such possibilities is most bewildering, and to quote from an address by Professor Jos. W. Richards referring to electrometallurgical progress, "We are so overwhelmed by new things of possible use to science or industry, that we can at most investigate only a small fraction of them. It is a virgin continent of undeveloped possibilities."

ADVANTAGES OF ELECTRIC FURNACE

The electric furnace owes its place in the scientific and industrial world to certain characteristics which it possesses and to the advantages which it offers over other means of generating heat, the principal one being the high degree of temperature which is made available. An interesting comparison might be worked out showing that civilization progresses in a rate proportional to the utilization of heat energy in its highest degree of concentration. Each additional degree of temperature which can be produced and kept under control shows itself capable of new and useful purposes, and the electric furnace has added such an extension to the range of available temperatures that it has almost doubled that previously available.

Limitations. It simply requires the passage of the electric current through a conducting medium to produce heat, the intensity of which depends upon the amount of current which passes. Inasmuch as most substances retain their conductivity at high temperatures, the degree of intensity which is theoretically possible is unlimited. Practically, however, limitations are placed upon it through the physical difficulties of keeping the conducting medium and the furnace walls in place. The temperature is limited by the fusing point of the material, while it retains its solid condition; when fusion commences, the difficulties of containing the melted material begin, and the temperature is limited by the point of vaporization.

When volatilization begins, the gaseous materials escape from the field of action, carrying away the heat, as rapidly as it is supplied to the furnace, in the form of latent heat of volatilization or energy stored up as potential chemical energy. It is true that the temperature of volatilization might be increased by subjection to high pressure, but this involves the construction of a container which can be made only of solid materials which will not fuse at the higher temperatures.

The electric arc maintained through a carbon vapor furnishes, perhaps, the highest temperature attainable, a temperature which is usually considered definitely fixed by the volatilization of carbon. On account of the limitations of our methods of measuring these high temperatures, the exact value to be assigned to the temperature of the electric arc cannot be stated, though the most satisfactory measurements give values ranging between 3600° and 4000° C. Whether or not this is the ultimate limit to be attained by electrical means is difficult to say. There is, of course, the possibility of exceeding it by maintaining the arc under a high atmospheric pressure, or by feeding electrical energy to the arc more rapidly than it can be dissipated by the volatilization of carbon, or, in other words, superheating the carbon vapor. Such speculation, however, is not necessary to show that the electric furnace has unbounded possibilities, since the range of temperatures below that of the ordinary arc offers an unlimited field for usefulness.

Comparison Between Electrical and Fuel Heating. While the attainment of high temperatures was the first achievement which called attention to the electric furnace and found many technical uses for it, the later developments have been in the direction of using electrical heating in competition with the various metallurgical processes where the combustion of fuel is employed. There are some who doubt the ability of the electric furnace to make inroads upon the fields occupied by other types of furnaces, and maintain heat energy from electricity to be entirely too costly, arguing as follows:

TABLE III

Relative Fuel Costs

Source of Heat	B. t. u. at Cost of One Cent
Coal at $2.50 per ton	112,000 B. t. u.
Natural gas at 20c per M	45,000 B. t. u.
Oil at 4c gallon	32,000 B. t. u.
Producer gas at 4c per M	37,500 B. t. u.
City illuminating gas at $1.00 per M	6,000 B. t. u.
Electrical energy at 10c per kw. hour	340 B. t. u.
Electrical energy at 1c per kw. hour	3,400 B. t. u.
Electrical energy at ¼c per kw. hour	13,600 B. t. u.

Cost of Heat from Fuels. A cheap source of heat energy is coal. On the assumption that one ton of a good grade of coal costs $2.50 and during combustion liberates heat to the extent of 14,000 B. t. u. per pound, the quantity of heat available for one cent will then be 112,000 B. t. u. From producer gas at four cents per thousand cubic feet and containing 150 B. t. u. per cubic foot, the heat attainable for one cent is 37,500 B. t. u. With city illuminating gas, of a calorific value of 700 B. t. u. per cubic foot and costing $1.00 per thousand cubic feet, we have 6000 B. t. u. available at a cost of one cent.

Cost of Heat from Electrical Energy. Electrical energy as distributed for lighting purposes costs in the neighborhood of ten cents per kilowatt hour. When freed from the cost of distribution and if delivered in large quantities without expensive transmission, this energy may be obtained for from one to two cents per kilowatt hour and from waterpower plants it is being sold at even lower prices, two cents per kilowatt hour being near the low limit. One kilowatt hour of electrical energy, when transformed into heat, furnishes about 3400 B. t. u., or, in other words, the heat equivalent of one kilowatt hour is represented by this figure.

Table III gives an idea of the relative cost of heat units obtained by different methods.

From Table III, it is evident that electrical heating with the lowest cost of energy obtainable is over eight times more costly than where heat is obtained from coal. The electric furnace, however, has advantages of such importance that this relative cost of heat units does not constitute a serious handicap for such a furnace. The

TABLE IV

Heat Efficiencies of Furnaces

Kind of Furnace	Efficiency
For generation of steam from coal	50% to 60%
Blast furnace for manufacture of iron	52% to 66%
Open hearth furnace for steel	10% to 12%
Reverberatory furnace	5% to 8%
Crucible steel furnace	2% to 4%
Retort furnace for zinc	2% to 3%
Electric furnace—for graphite	75%
Electric furnace—for fused Al_2O_3	75%
Electric furnace—for iron and steel	50% to 80%

advantages of the electric furnace may be summarized chiefly as follows:

Electrical energy gives "pure, unadulterated heat" to the material which is to be treated, while many of the combustion methods involve the transmission of heat by means of the gaseous products of combustion. The efficiency of electrical heating is, therefore, greater. Table IV gives a numerical idea of the heat efficiencies of various types of industrial furnaces.

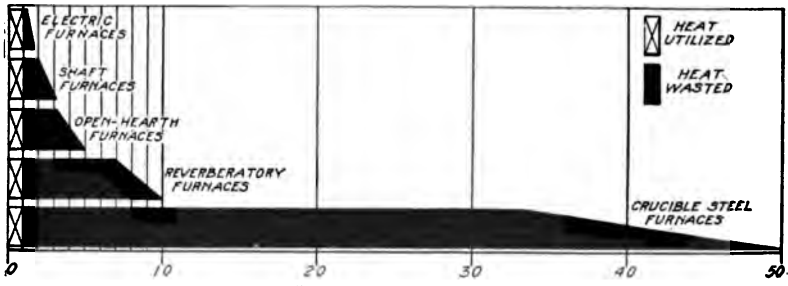


Fig. 21. Losses of Heat in Melting Metals
Copied from The Electric Furnace, by Alfred Stansfield

Fig. 21 gives a graphical representation of the heat lost and utilized in various types of furnaces for melting metals.

The chief reason for the very low efficiencies of combustion furnaces is that the waste products of combustion carry away most of the heat. In a crucible furnace this loss is so great that as much as 98 per cent of the heat energy is wasted. Radiation losses from combustion furnaces are usually greater than for electric furnaces on account of the larger size of the former.

Economy of Electric Heating. As shown in Tables III and IV, 112,000 B. t. u. are available for one cent's worth of coal, but if this heat is used for melting steel in a crucible furnace, only two per cent or 2240 B. t. u. are useful. With electric heating, however, at one-quarter cent per kilowatt hour at an efficiency of 80 per cent, 10,880 B. t. u. are actually available, and the electric heating thus becomes far cheaper even for the lower temperature metallurgical operations.

Added to this advantage of high efficiency, the electric furnace has the merit of making available high temperatures; of making possible a direct application of the heat to the material heated; of making small furnaces do the work of larger furnaces. The volumes of gaseous products which have to be handled are much less with the electric furnace, and this is also important because the gaseous products of combustion frequently interfere with the desired chemical reactions. The electric furnace can be operated with either an oxidizing or reducing atmosphere. Not the least among the advantages of the electric furnace is the more efficient use of refractory materials which is possible. The limitations upon almost all types of furnaces lie in the limitations of refractory materials which are available. In a crucible type of combustion furnace, the heat must pass through the refractory walls to get at the substance to be heated. This means that the heat to pass through this refractory material must have a higher temperature outside than inside. If, for example, iron is to be melted, having a melting temperature of 1500° C., the temperature on the outside of the crucible must be considerably higher than this. On the other hand, if electrical heating can be applied inside of the crucible, the crucible linings may be at a somewhat lower temperature than 1500°.

TYPES OF ELECTRIC FURNACES

While the transformation of electrical energy into heat energy is in itself a simple operation capable of being carried on at an efficiency of one hundred per cent, there are innumerable modifications of furnace construction and operation. Electric furnaces may be classified in two main classes, viz., the arc furnace and the resistance furnace.

Arc Furnace. The electric arc had its first great use for illumination purposes, depending for its usefulness on the fact that an arc maintained between two carbon terminals raises these terminals to such a high temperature as to give off intense luminous radiations. Fig. 22 illustrates such an arc, maintained by the flow of direct current. The arc itself consists of a crater at each of the electrodes and a conductive gaseous medium connecting them, the location of the highest temperature being at the positive crater. This temperature is probably the highest attainable by any known means, being that of the vaporization of carbon.

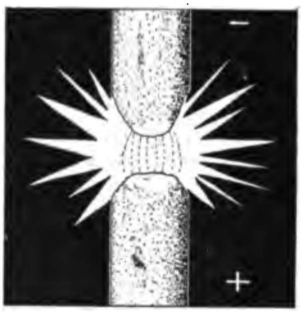


Fig. 22. The Electric Arc
Copied from The Electric Furnace, by Alfred Stansfield

Either direct or alternating current may be used for maintaining an arc and thus we have a subdivision of arc furnaces into the direct-current and the alternating-current types.

In electric furnace terminology, the term electrodes is used in a different sense from that implied in electrolytic cells, being the terminals or conducting bodies furnishing the entrance and exit of the current to and from the furnace. Carbon or graphite is almost universally employed as electrodes for the arc furnace because of the ability of these materials to withstand the intense heat without melting.

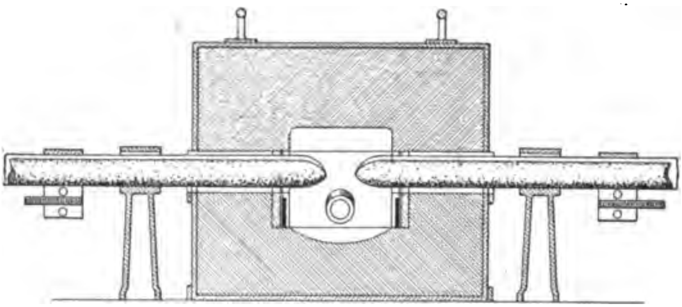


Fig. 23. Small Arc Furnace
Copied from Electric Furnace, by Wilhelm Borchers

The arc furnace differs from the lighting arc mainly in its size and far greater power consumption and in its being enclosed within refractory walls to prevent the escape of the heat. The increased power consumption is brought about by increased flow of current at only slightly higher voltages than those used in the arc lamp. The pressure required to maintain a powerful arc furnace ranges usually between 50 and 100 volts, while the current consumption may be hundreds and even thousands of amperes.

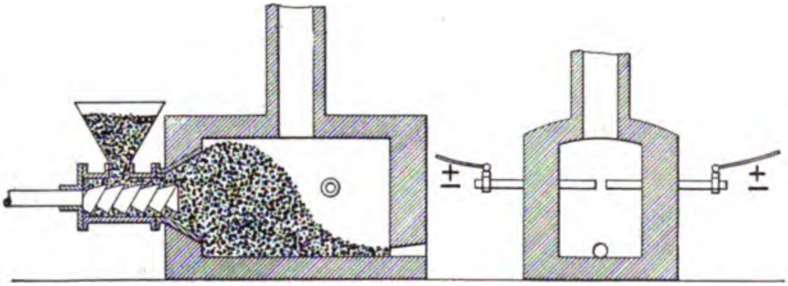


Fig. 24. Sections of an Arc-Muffle Furnace
Copied from Electrothermal and Electrolytic Industries, by Ashcroft

A small arc furnace is illustrated in Fig. 23, where the terminals of two horizontal carbon electrodes are enclosed in an iron box lined with a heavy layer of lime, magnesite, or other highly refractory material. Such a furnace has extensive use in small laboratory operations, where the heat of the arc is radiated from the craters, reflected by the walls, and conducted by the enclosed gases to the crucible or material resting on the bottom of the furnace.

Fig. 24 shows diagrammatically the same type of furnace applied to the treatment of an ore fed continually into the side of the furnace, the volatile products passing up the chimney, and the liquid metal or slag running off at the bottom.

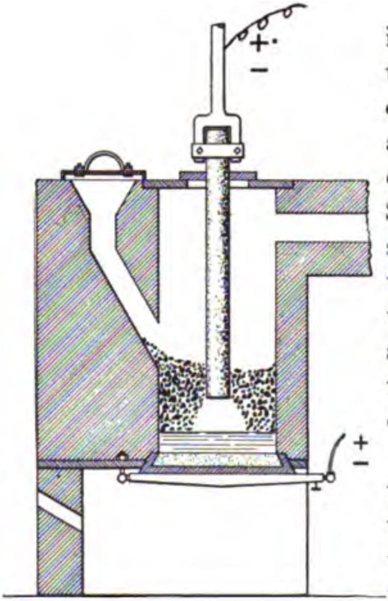


Fig. 25. Furnace with Embedded Arc
Copied from Electrothermal and Electrolytic Industries, by Ashcroft

Another modification is illustrated in Fig. 25, where the arc is actually embedded in the mass of material which is being treated.

In this case the upper electrode consists of carbon and the lower one of the liquid metal or material which is being reduced. In such form of furnace, calcium carbide may be produced, or the reduction of iron oxide may be effected.

An arc furnace in which two arcs are maintained is illustrated in Fig. 26, where *M* represents a mass of molten iron covered by a layer of slag *S*. The current entering one of the carbon electrodes passes through the arc and the slag to the iron, thence through the slag and arc to the other terminal electrode. This is a type of furnace commonly used in the electric steel industry.

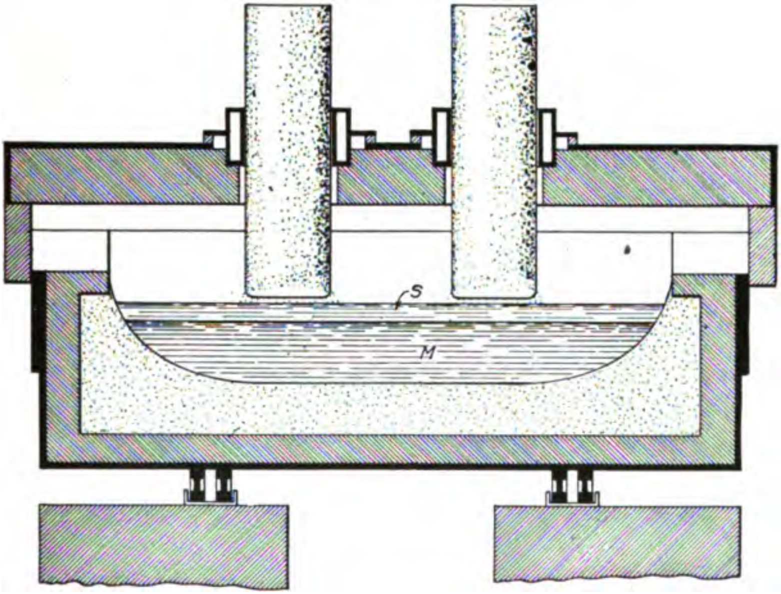


Fig. 26. Furnace with Two Arcs
Copied from The Electric Furnace, by Alfred Stansfield

Resistance Furnaces. The resistance type of furnace depends upon the fact that in passing current through a conductor heat is generated, the temperature being higher the greater the amount of current. Thus heat may be generated within the material under treatment if such material has the proper degree of conductivity. Or the heat may be conducted from the conductive mass carrying the current to a surrounding or adjacent material.

The term "resistor" is used in designating that portion of a resistance furnace which conducts the current and in which the heat is generated. This resistor may be any one of a large variety of materials, such as granulated or crushed carbon or coke, fused metals, slags, or, in fact, any material which is conductive in the liquid or solid state.

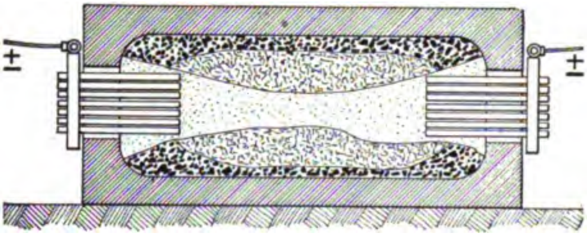


Fig. 27. Resistance Furnace for Graphite and Carborundum
Copied from Electrothermal and Electrolytic Industries, by Ashcroft

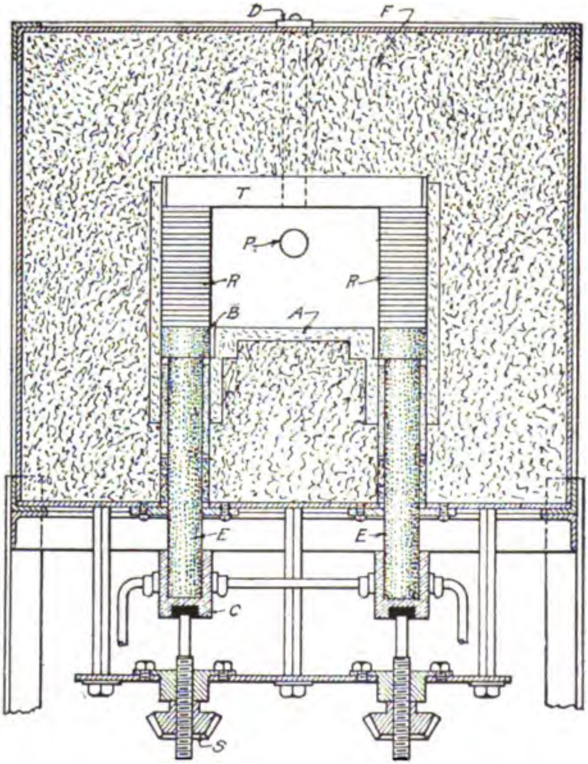


Fig. 28. Section of Muffle Furnace
R—Carbon resistor plates; T—Carbon top plates; B—Graphite bottom plates; E—Graphite electrodes; S—Regulating screws and gears; A—Special refractory cement; F—Fire brick heat insulation; P—Pyrometer hole; D—Draft hole and cover.
Courtesy of Hoskins Manufacturing Company

Fig. 27 shows a common type of resistance furnace, such as is used in the manufacture of graphite and carborundum. The resistor is the central column of coke, between the two terminal carbon electrodes, and surrounded by the layers of material under treatment, the whole being enclosed within the retaining walls.

Figs. 28 and 29 show a type of resistance furnace in extensive use for the heat treatment of metals and for other purposes where muffle heating is desirable on a small scale. The sectional view shows two tiers of carbon plates *R*, an upper graphite plate *T*, the carbon plates being pressed upward against this plate by graphite electrodes *E*. The heat is generated by the passage of the current from plate to plate, and the degree of contact is varied by the adjusting wheels at the bottom of the furnace. By this adjustment, and by varying the pressure of the current supplied to the furnace, the desired degree of heat can be attained.

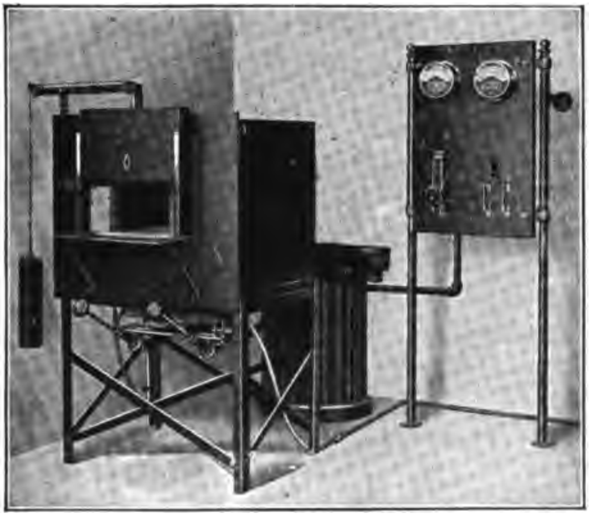


Fig. 29. Hoskins Type FC Electric Furnace
Courtesy of Hoskins Manufacturing Company

COMMERCIAL PROCESSES

NON-METALLIC COMPOUNDS

Calcium Carbide. Lime and carbon mixed together and heated to a high temperature react according to the following equation:

$$CaO+3C=CaC_2+CO$$

That is, the carbon acts as a reducing agent to remove the oxygen from the lime and additional carbon unites with the lime to form calcium carbide.

The temperature required to bring about this reaction is higher than can be furnished practically by combustion furnaces. Electric heating is necessary, therefore, in the production of this compound, and this use has constituted an important electric furnace industry since 1895.

Calcium carbide is a crystalline product which has the property, upon adding water, of liberating gas according to the following reaction:

$$CaC_2+2H_2O=C_2H_2+Ca(OH)_2$$

This gives C_2H_2, or acetylene, which has its most extensive application as an illuminant and it is chiefly for the production of this gas that calcium carbide is manufactured.

The process is a simple one. The raw material consists of an intimate mixture of a good grade of lime and of carbon in the form of charcoal, coke, or anthracite coal.

There are two main types of furnaces used in the treatment; in one type the calcium carbide is removed from the furnace in the form of a solid block; in the other type it is tapped from the furnace in a liquid state.

In the former type, the heating may be effected by means of an arc drawn between two carbon electrodes, the mixture being fed to the heat zone where the reaction takes place and the molten carbide flows into a mass which solidifies in the cooler portion of the furnace. The earlier methods consisted in running a box type of furnace until a certain amount of carbide had accumulated therein, when the current was interrupted and the solidified material removed and broken up for shipment. An improvement in this type consisted in forming the calcium carbide in a rotating type of furnace as illustrated in Fig. 30. The solidified core is rotated away from the arc terminals at a rate proportional to the formation of the carbide. On the opposite side of the furnace, the core is removed by breaking off pieces. This type of furnace is an improvement which insures continuous operation.

In the tapping type of furnace, an iron container lined with a refractory material with a bottom layer of carbon contains the charge. An electrode is lowered from above, and 200 kilowatts and upward of alternating energy is supplied. The higher temperature maintains the carbide in a molten condition and at regular intervals it is tapped from the furnace into iron ladles.

In either the tapping type or the rotating solid core type, continuous operation of the furnace is possible.

The energy consumption per pound of carbide is stated to be in the neighborhood of two kilowatt hours.

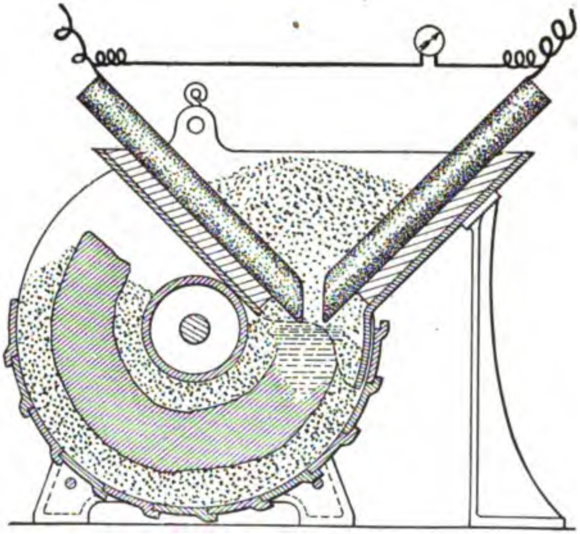


Fig. 30. Rotary Calcium Carbide Furnace
Copied from Electric Furnace, by Wilhelm Borchers

Silicon Products. Just as lime may be acted upon by carbon at high temperatures so reactions likewise take place in mixtures of carbon and silicon oxide or sand. Electric furnace temperatures are the most practical for bringing about these reactions, of which there are several possible ones depending upon the temperature and other working conditions.

One reaction may be represented by the equation

$$SiO_2 + C = SiO + CO$$

Silicon monoxide, SiO, is a brown powder. Its suggested uses are as a pigment, as a reducing agent, and as a heat insulating material. Thus far, however, it has been an unimportant technical product.

Another reaction proceeds according to the equation

$$SiO+C=Si+CO$$

That is, the silicon monoxide may be reduced by the carbon to the element silicon with the accompanying evolution of carbon monoxide. Large quantities of silicon have been produced according to this method and a material which was formerly a chemical curiosity is easily produced in large quantities. A construction of furnace which has been proposed for the production of silicon is illustrated in Fig. 31. The electric terminals of the furnace consist of two carbon electrodes introduced horizontally. Connecting these electrodes is a pile of carbon slabs acting as a resistor where the heat is generated. This resistor is surrounded by a mixture of sand and carbon and the molten silicon settles to the bottom and flows through the openings into the lower chambers. This so-called metallic silicon has a purity of about 95 per cent. It is a dense crystalline substance with a dark metallic luster. It has a melting point somewhat less than that of pure iron. Among its uses, it is employed as an addition agent to steel and it is also manufactured into crucibles and containers for resisting acids.

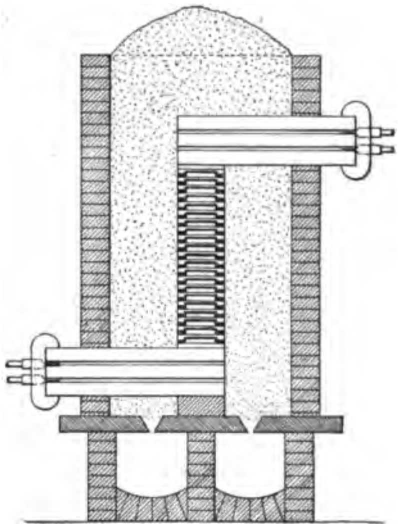


Fig. 31. Silicon Furnace
Courtesy of Electrochemical Industry

Still another reaction which may take place between sand and carbon is represented by the equation

$$SiO_2+3C=SiC+2CO$$

Carborundum. The silicon carbide, SiC, or carborundum, as it is generally known, is the most important of the products obtained from the union of the reactions between silicon and carbon. It was discovered, in 1891, by Acheson, who recognized in the hard iridescent crystal produced a material valuable as an abrasive agent.

The hardness of this material is only slightly less than that of the diamond and it is now produced in large quantities on account of this useful property.

The electric furnace is a simple type of resistor furnace in which a conductive core of carbon about three feet in diameter is placed between the end carbon electrodes which are held stationary in fire-brick walls. Packed around this carbon core is a mixture of finely ground anthracite coal, or coke, with a pure silica sand, mixed approximately according to the chemical formula given above. In addition to these materials some sawdust and salt are added, the purpose of the former being to increase the porosity of the charge and allow the ready escape of the carbon monoxide gas. The presence of salt is claimed to assist in the removal of some of the metallic impurities in a volatile state.

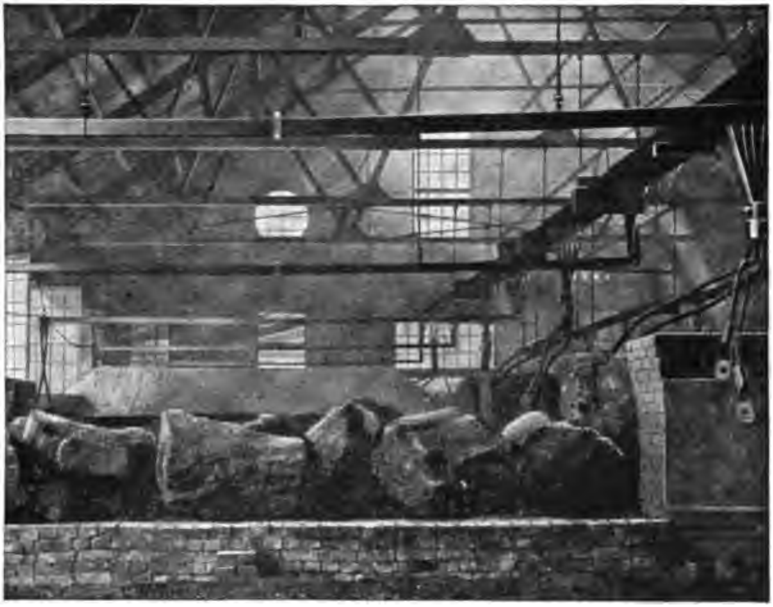


Fig. 32. Carborundum Furnace
Courtesy of The National Magazine

A 2000-h.p. furnace is approximately 30 feet long and takes 6000 amperes at a terminal pressure of about 230 volts. As the core heats up, its resistance decreases so that for a constant power consumption an increased amperage at a lower voltage must be supplied. At the end of the run the current may be 20,000 amperes at a pressure of 75 volts.

When the reaction has been completed, the furnace is allowed to cool down, the side walls are removed, and the carborundum is found as a thick shell around the inner core. Fig. 32 illustrates one of these furnaces in the process of dismantling after a run.

In the operation of carborundum furnaces, considerable quantities of graphite have been produced, especially in the hotter portions of the charge. This is explained by the fact that carborundum when heated to 2200° C. decomposes, the silicon being vaporized away, leaving the carbon in the form of graphite. According to the reaction

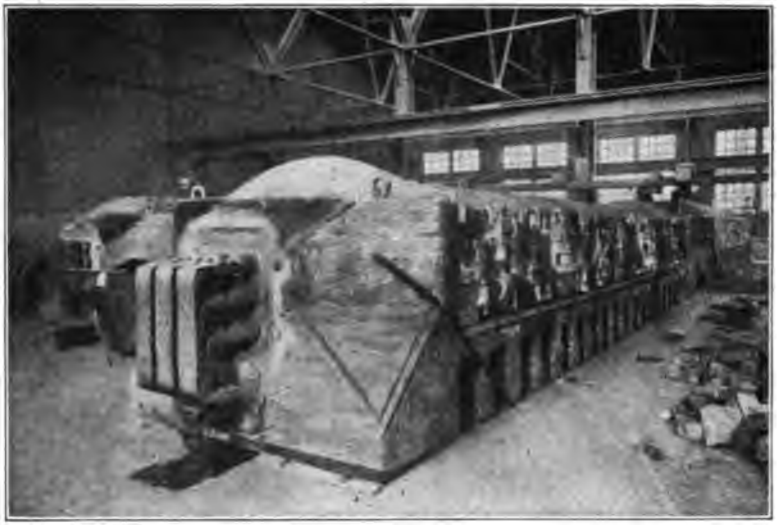


Fig. 33. Graphite Furnace
Courtesy of International Acheson Graphite Company

$$SiC = Si + C$$

Graphite. One of the most spectacular, as well as important, achievements of the electric furnace is the production of artificial graphite. To Mr. Acheson belongs also the credit of its development. He found that at certain high temperatures carbon in the form of coal or coke is transformed into graphite. It has been the prevailing belief that this conversion is brought about through the aid of certain oxides, such as those of silicon, aluminum, and iron. The exact way in which these oxides act is not clear, the supposition being that they act as a catalytic agent. Artificial graphite is now produced in many different grades and the number of its uses is steadily increasing.

The type of furnace for the production of graphite powder is similar to that of the carborundum, having permanent end walls with electrodes, a fire-brick bed, and removable side walls of refractory brick. When charging, a layer of carborundum sand is first placed on the bed to protect it from fusion. The charge is then filled in up to the lower portion of the electrodes. It consists usually of anthracite coal, ground to a varying size. A core of graphitized material is employed on account of its ability to conduct the current and serve as a resistor. Finally more of the charge is placed around and above the core and the furnace is covered with a layer of refractory sand to prevent oxidation.

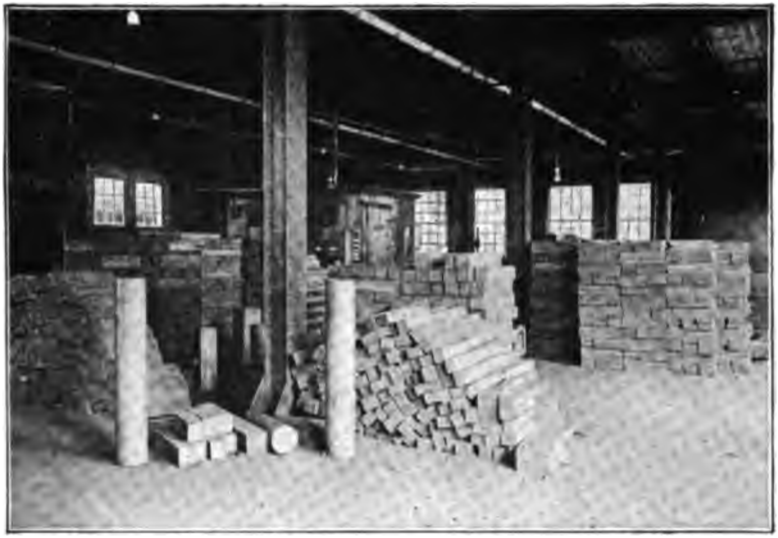


Fig. 34. Graphitised Electrodes
Courtesy of International Acheson Graphite Company

A 1000-h.p. furnace is 30 feet long with a core diameter of 2 feet. The current increases from 3700 amperes to 9000 amperes during heating, while the voltage decreases from the starting value of 200 down to about 80. A run may be 24 hours in length, after which the furnace is cooled sufficiently for dismantling. A graphite furnace in operation is illustrated in Fig. 33.

For the manufacture of graphite in the form of blocks or rods suitable for electrode purposes, a similar type of furnace is used. The ungraphitized articles are made from a mixture of amorphous carbon or finely powdered petroleum coke, pressed and molded with a pitch binder, after which it is calcined in a gas-fired furnace. To convert these carbon bodies into graphite simply means the application of a sufficient amount of heat, to secure which the carbons are packed between the end electrodes of the graphite furnace in a bed of conductive granulated carbon or graphite. The operation is similar to that of the graphite furnace just described.

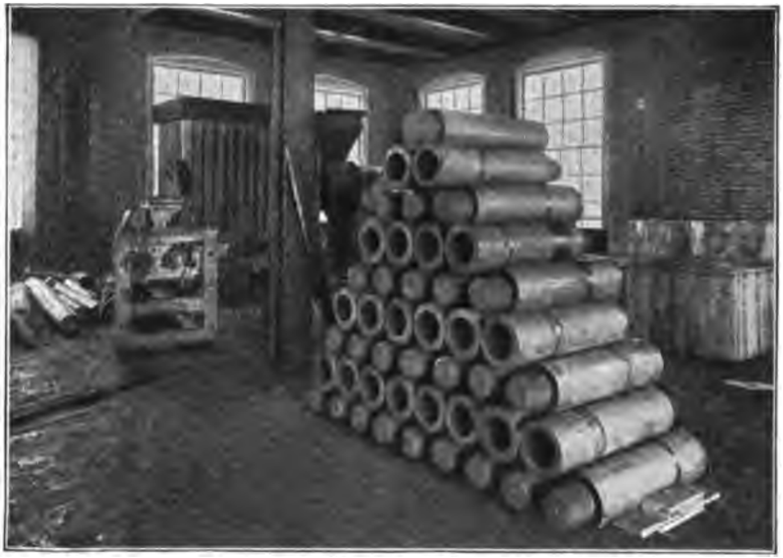


Fig. 35. Graphite Electrodes for Furnace Work
Courtesy of International Acheson Graphite Company

The industry is of interest to the electrochemist not only as being an electrochemical industry in itself but also as furnishing a most valuable form of carbon for electrolytic and electric furnace work. Fig. 34 illustrates various forms of graphite electrodes while

Fig. 35 illustrates large graphitized carbon cylinders arranged to be fitted together for use in electric furnaces.

Alundum. Alundum is another electric furnace product which has a commercial value as an abrasive, also as a highly refractory material. Alundum is the trade name given to fused aluminum oxide. It is made by first purifying bauxite and then fusing it in an electric arc furnace. The furnace consists of a circular hearth of carbon blocks with a removable wall of sheet iron, water-jacketed throughout. Two carbon electrodes introduced from above convey the alternating current to and from the furnace. When a sufficient quantity of the fused material has formed, the solidified material is removed and broken up, crushed, and graded.

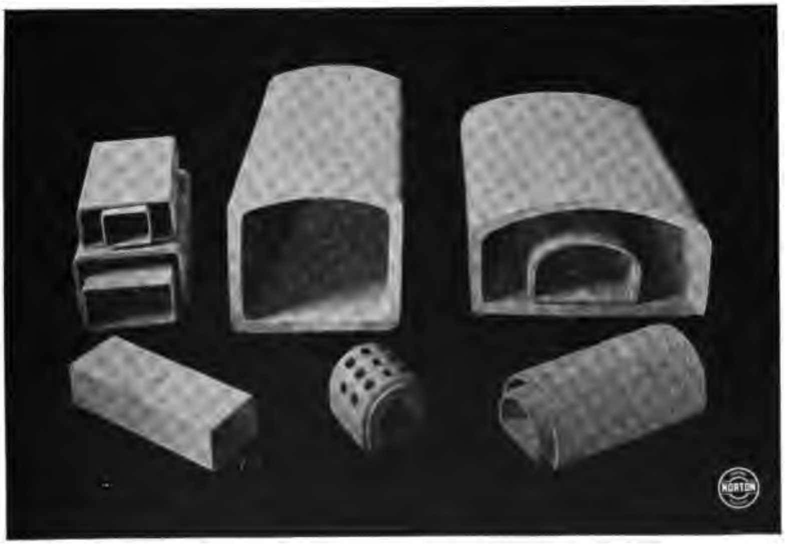


Fig. 36. Alundum Muffles
Courtesy of The Norton Company

From the finely crushed material, grinding wheels are formed, and it is also used in the construction of crucibles and muffles such as illustrated in Fig. 36.

Carbon Bisulphide. One of the big electric furnace achievements is its recently attained monopoly in the production of carbon bisulphide. This is a liquid of the chemical composition of CS_2. The Taylor furnace, by which practically all of the supply of material used in this country is manufactured, is of the resistor type, illustrated in Fig. 37. It is a fire-brick structure, enclosed in a strong iron shell. The resistor consists of pieces of coke or of broken electrode carbons fed into and occupying the space at the bottom of the furnace, and terminal electrodes of carbon supplying the current to this resistor material. The form of carbon used for the resistor does not react readily with sulphur, but the contrary is true of the charcoal which is fed in at the top of the furnace and occupies most of the space in the upright cylinder. The sulphur is introduced into the hearth of the furnace below the electrodes, where it is vaporized and passes upward through the charcoal where the reaction takes place. The carbon bisulphide vapors leave the furnace at a comparatively low temperature.

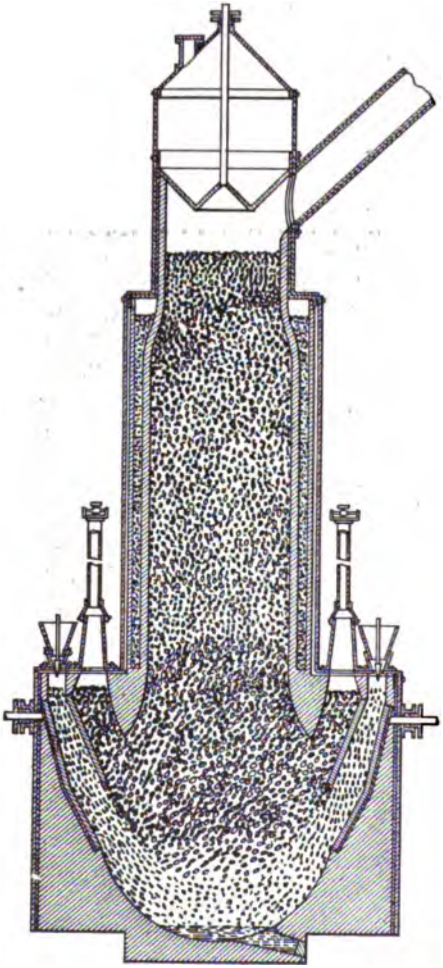


Fig. 37. Carbon Bisulphide Furnace
Copied from Production of Carbon Bisulphide, by Taylor

ELECTRIC FURNACES IN THE STEEL INDUSTRY

After years of experimental and exploitation work, the electric furnace has reached a position of commercial importance in the iron and steel industry. While at present a comparatively small tonnage of steel is influenced by electric furnace development, there is a general prediction that the electric furnace is going to become of great importance.

The different ways in which the electric furnace may be used in this industry may be classified as follows:

(1) The direct reduction of iron from its ores, producing either a pig iron or finished steel.
(2) Replacing or supplementing the existing types of metallurgical furnaces for the manufacture of steel from pig iron.
(3) The replacement of the crucible process by the electric furnace.
(4) For the heating of billets and bars, for the purpose of heat treatment or for rolling and drawing purposes.

Direct Reduction of Iron from Its Ores. For this purpose the electric furnace must replace the ordinary blast furnace in which the iron ore is reduced by being mixed with coke or other form of carbon, the heat for reduction being supplied by the combustion of the fuel. This type of furnace has a high thermal efficiency, being above 50 per cent, and from the standpoint of cost of energy, the electric furnace has little opportunity for competing. The electric furnace, however, supplies heat by the transformation of electrical energy, while the heat from the blast furnace must be obtained from the combustion of the carbon in the furnace charge. Therefore, with the electric method a material saving can be made in the amount of coke or other form of carbon used, and this method is therefore advantageous where fuel is scarce and waterpower plentiful. Furthermore, a higher temperature can be obtained by the electrical method of heating so that certain refractory ores can be reduced in the electric furnace which would clog up the ordinary blast furnace.

For the successful direct smelting of iron ores there is required a very cheap source of electric power in a location where there is a market for the product, also a convenient source of iron ore, and where a saving in the amount of carbon used is of importance; in other words, where the price of coke or charcoal is high. These conditions are found in only a few places, such as along the Pacific Coast, where extensive experiments along this line have been carried out. In the industrial centers, however, the direct reduction of iron ores does not seem to be practicable by the electrical method.

Manufacture of Steel from Pig Iron. Steel is commonly made from pig iron by taking the molten iron as it comes from the blast furnace and putting it through a refining operation, in the Bessemer or open hearth, or other similar refining process. If the refining is not done in conjunction with the smelting operation, the pig iron is shipped to the place where the refining plant is installed, and in this case the pig iron must first be melted up.

It is evident that there are various ways in which the electric furnace may be employed, either to replace or to supplement the ordinary refining operations. Instead of running the molten pig iron into the Bessemer converter, the hot metal may be run into an electric furnace and the refining operation carried on by the addition of the electrical heat which may raise the charge to any desired temperature. On the other hand, the electric furnace may be used only as a finishing step after a certain amount of refining has been done by the ordinary process.

Temperature is an important factor in the refining operation, and under the higher temperatures available in the electric furnace, the refining may be carried out more quickly and to a higher degree than is possible by the fuel methods of heating. For such purpose the electric heating has a high thermal efficiency as against the much lower thermal efficiency of the gas- or fuel-heated furnace; and in taking the molten material from the blast furnace or melting furnace, heated by fuels, the electric furnace is called upon only to do the high temperature, or critical, part of the work. It is claimed that by its use a specially high quality of steel may be secured and that the uniformity of the product is much greater than is otherwise attainable.

Manufacture of Crucible Steel. In the manufacture of high grade tool steel, the electric furnace seems to have its most marked field of usefulness.

The crucible process, as ordinarily carried out, consists in melting up in graphite or plumbago crucibles a commercial grade of pure iron and adding the purifying and alloying agents which are required. The crucibles, costing about $2.50 each, will hold about 100 pounds of metal and can be used six or seven times. These crucibles are heated by the products of combustion and the thermal efficiency is very low, being in the neighborhood of two per cent. The electric furnace with its 80 per cent efficiency is, therefore, able to compete profitably, and the high cost of crucible maintenance gives the electric furnace another opportunity to win out in the struggle for supremacy.

Arc Type of Furnace for Iron and Steel. The various forms of the arc type of furnace are playing the more important part in the electrometallurgy of iron. As illustrative of the leading forms of arc furnace, reference may be made to Fig. 38, showing the Stassano, the Heroult, and the Girod methods of operation.

Stassano Furnace. This furnace in practice assumes several forms. It consists of a thick walled, rectangular chamber with a slightly arched roof. The electrodes are introduced into the side of the furnace and the raw material charged in at the ends. Tapping holes are provided for the slag and the finished steel. Another modification takes a circular form in which the entire furnace is slightly inclined and rotated slowly about its axis so as to give some agitation to the furnace contents. The fixed type of furnace has been designed up to a capacity of 750 kw., while the rotating furnace has a capacity of about 200 kw. This furnace operates at a pressure of about 150 volts, somewhat higher than is usual with arc furnaces on account of the long arc which is employed.

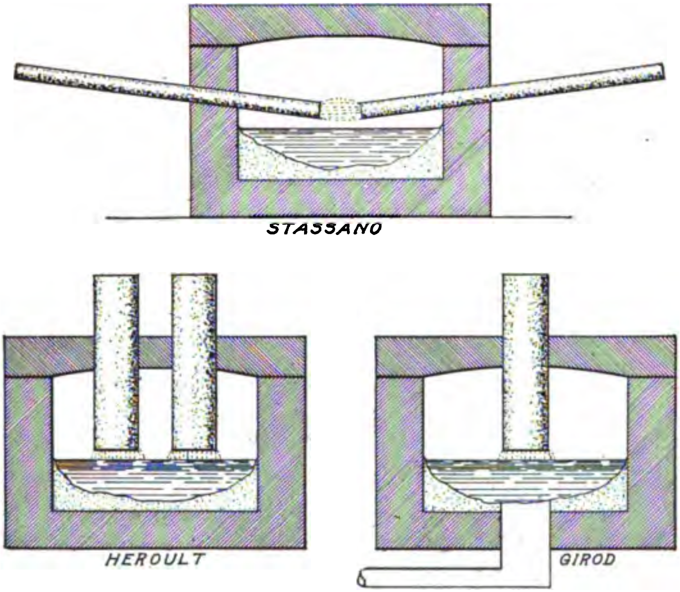


Fig. 38. Sections of Three Representative Types of Steel Furnaces

Heroult Furnace. This furnace, which appears to be most widely used in this country, is of a simple construction consisting of a shallow hearth lined with refractory material and roofed over with silica brick. The contents are discharged by tilting the entire furnace, together with the electrode supports. Two electrodes enter

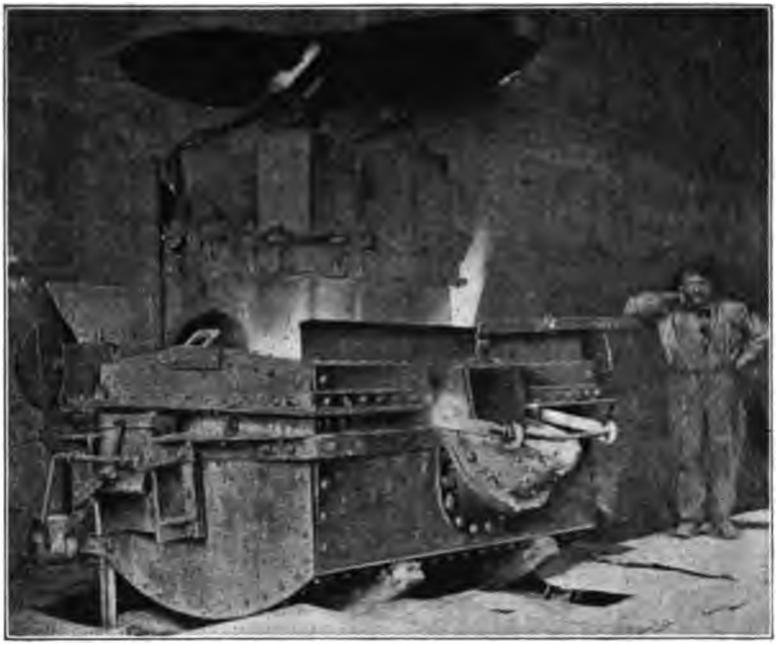


Fig. 39. Heroult Furnace in Operation
Courtesy of Société Electro-Métallurgique Française

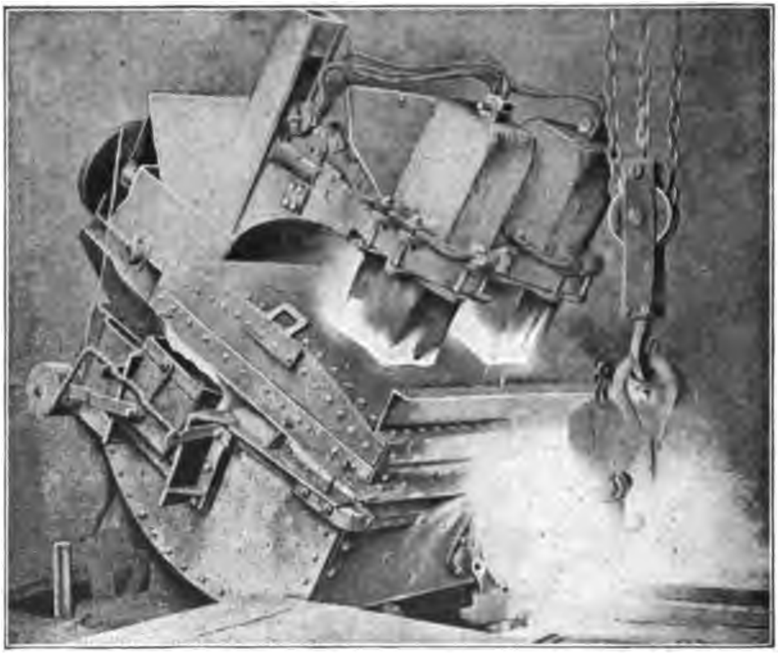


Fig. 40. Heroult Furnace Discharging Molten Steel
Courtesy of Société Electro-Métallurgique Française

vertically through openings in the roof and project down to within one or two inches of the surface of the bath. They may be water cooled at the points where they pass through the roof as well as at the cable connections. Furnaces of a capacity of from 15 to 20 tons have been used and operated at pressures of from 45 volts to 100 volts, depending upon the energy input. A 15-ton furnace requires

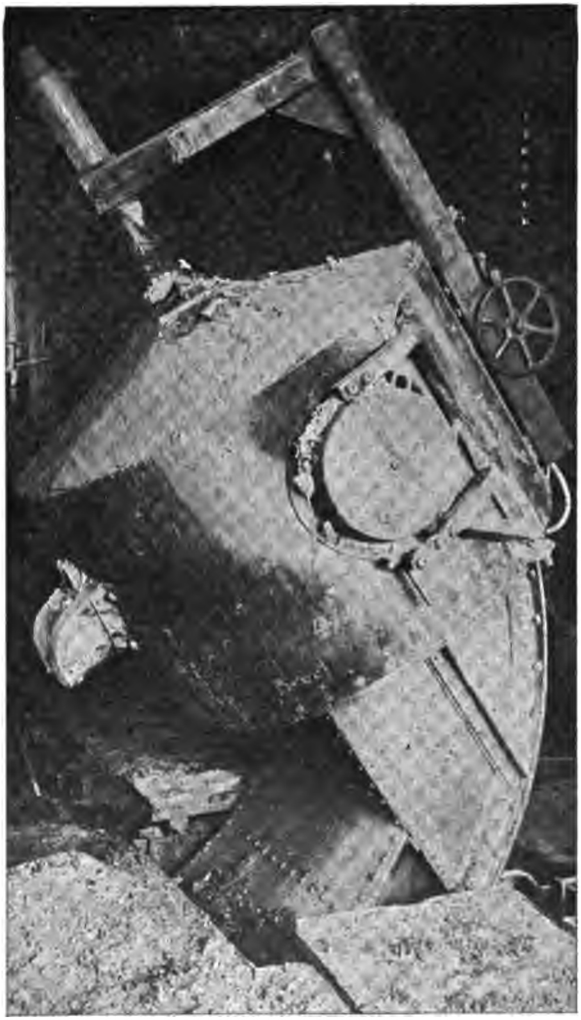


Fig. 41. Steel Furnace About to Pour Its Charge
Courtesy of The Iron Age

up to 2000 kw. Fig. 39 illustrates the Heroult type of furnace in operation, while Fig. 40 shows the tilting operation for discharging the finished product.

Girod Furnace. This furnace differs from the Heroult in that the current enters through the electrode in the roof of the furnace, Fig. 41, arcs across to the slag, then through the steel bath, finally leaving by one or more steel electrodes embedded in the refractory hearth material. Thus instead of having two arcs in series there is only one. The voltage of this furnace is, therefore, approximately half that of the Heroult type and with furnaces of equal load the current is necessarily twice as great. These furnaces have been built up to capacities of 15 tons. The voltage varies between 55 and 75 volts and a 300-kw. furnace will take from 5000 to 5500 amperes and a 1200-kw. unit will take 20,000 amperes.

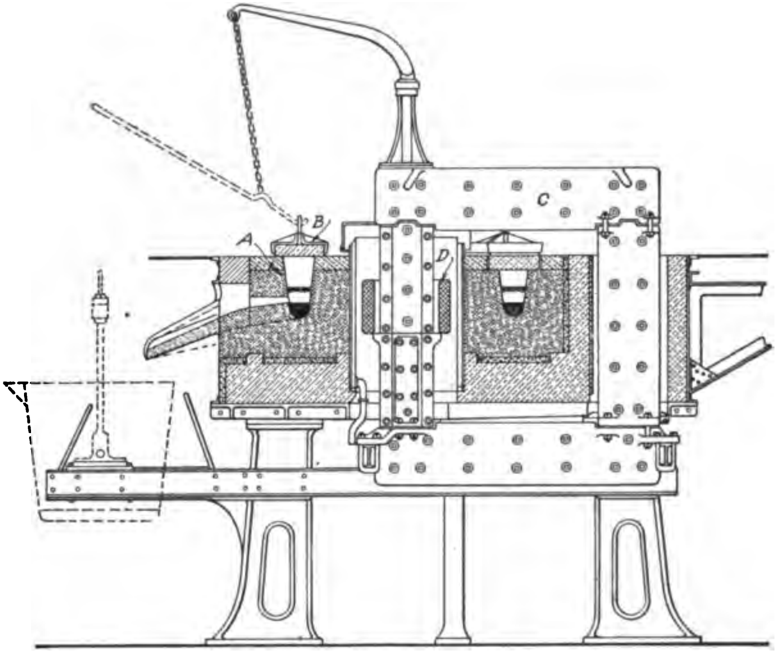


Fig. 42. Cross Section of an Induction Furnace
Courtesy of American Electric Furnace Company

Induction Steel Furnaces. An important type of steel furnace is what is known as the induction type, whereby the use of electrodes is entirely avoided, as is also the contamination of the steel by pieces of carbon breaking off from the electrodes. The absence of carbon electrodes is made possible by causing the molten metal, in a continuous circuit, to carry the energy which is applied to it by magnetic induction. In other words, an induction furnace is a step-down transformer with a short circuited secondary consisting of a single turn of the molten metal. It is obvious that the molten metal must be confined in a channel surrounding the core of the transformer, which core is also wound with a winding of a suitable number of turns to correspond with the alternating voltage which is applied.

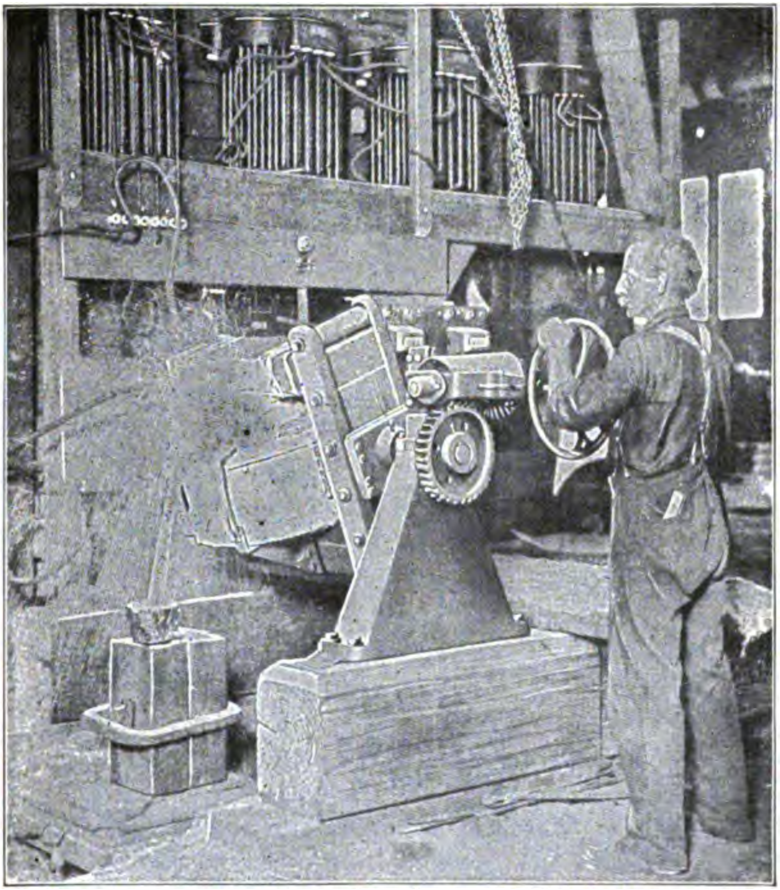


Fig. 43. Induction Furnace in Operation
Courtesy of American Electric Furnace Company

Fig. 42 shows the cross section of an induction furnace, *C* representing the iron core, or transformer, *D* the winding placed thereon, *A* the molten metal constituting the single turn secondary embedded in a refractory channel, and *B* the refractory cover for this channel.

To get such a furnace in operation, it is necessary that there be a continual metal mass, which is afforded by pouring molten metal into the furnace. When a pour is made from the furnace, care is taken to retain some of the metal to act as a starter for the next run.

As counterbalancing the obvious advantages, this furnace has losses and disadvantages which have restricted its general use. It is subject to magnetic and electrical losses due to hysteresis in the iron core, heat losses in the primary circuit, and magnetic leakage. Furthermore, there is a large heat radiating surface by reason of the long channel which must be employed for a given quantity of metal. Fig. 43 shows the operation of a small induction type of furnace.

ELECTRICAL DISCHARGE IN GASES

Thus far consideration has been given to the use of currents passing through solid or liquid conducting materials where comparatively low voltages are required; also to a certain vapor type of conduction in the low voltage electric arc.

Characteristics of Discharge. A new and rapidly developing field of applied electrochemistry utilizes phenomena attendant upon the application of high voltages to gaseous media. Fig. 44 conveys diagrammatically an idea of the relation of current and voltage when an increasing difference of potential is applied to two similar electrodes separated by air or other gas. As the voltage is increased from zero, there is little flow of current or, in other words, the electrodes are practically insulated. By sufficiently sensitive instruments a slight flow of current may be detected, as indicated by the portion of the curve marked "non-luminous discharge". This produces no physical or chemical effects and is unimportant from the practical standpoint. Upon reaching a certain voltage, however, there is a discontinuity of the curve, the current increases, and the discharge between the electrodes becomes luminous. The appearance and exact nature of this luminous discharge vary, being dependent upon whether direct or alternating currents are flowing, the shape of the electrodes, and various other factors. It is designated as a glow or brush discharge. The intensity becomes greater as the voltage increases, and when air is a medium, the oxygen is conveyed into ozóne.

The current for the brush discharge becomes a maximum at a certain voltage, indicated by the highest point on the curve, after which there is a more rapid increase in current, and a marked lowering of the voltage is necessary in order to keep the discharge under control. The discharge then assumes the form of the high tension arc. The sparking is very pronounced and the discharge is active in producing nitric oxide from the air. The fact that the voltage falls is due to the increased conductivity of the gaseous medium caused, in turn, by the higher temperature produced by the increased current. This form of arc has important technical uses which will be illustrated later.

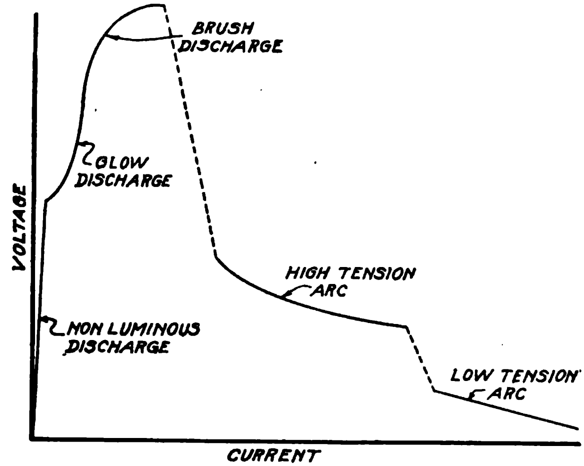


Fig. 44. Curve Showing Relation of Current and Voltage with Increasing Potential at the Terminals

If the current of the high tension arc is allowed to increase, a point is reached where the low tension arc is produced. This is a form of arc which has been previously considered in connection with arc lights and the arc furnace.

PRODUCTION OF OZONE

Ozone is a polymerized form of oxygen. It has a molecular formula of O_3 instead of O_2, the symbol for oxygen. In other words, a molecule has three atoms of oxygen instead of two. It has a powerful oxidizing property which makes it highly useful for bleaching, disinfecting, oxidizing oils, etc. Its most extensive use is for water purification.

Ozone from Oxygen. Oxygen can be converted into ozone by heating to a very high temperature and then suddenly cooling, but only small yields are produced by this method. The use of the silent electric discharge at room temperatures avoids this difficulty.

Siemens-Halske Ozonizer. A great number of forms of technical ozonizers have been proposed. The Siemens-Halske apparatus, indicated in Fig. 45, is an important type of commercial apparatus used in water-purification plants. It consists of an iron container provided with glass windows. Passing upward through the container are a number of vertical glass cylinders coated outside with a metal which serves as one electrode. In the center of these tubes are placed the other electrodes consisting of cylinders of aluminum foil. Water is run through the container outside of the tubes to keep the apparatus cool and keep up the efficiency. The air is previously dried by means of calcium chloride or some other suitable drying agent and passes along the annular spaces between the electrodes. The metal outside of the tubes is connected to one terminal of a high alternating pressure and the inner electrodes are

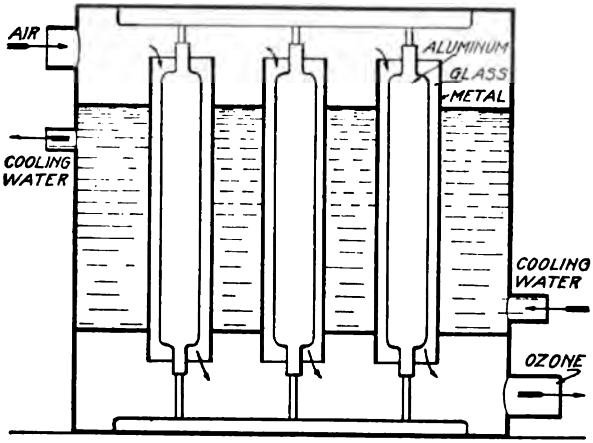


Fig. 45. Section of Siemens and Halske Ozonizer

connected to the other terminal. The iron container is connected to earth, thus preventing a risk to the operator.

A pressure of from 4000 to 7000 volts has been used on this type of ozonizer, and plants for water purification have been operated in Paris and St. Petersburg.

By placing the apparatus in a darkened room it is possible to tell from the luminous appearance whether it is working properly. It is claimed that with an expenditure of 57 kilowatt hours, a million gallons of water may be sterilized by this means. The method of sterilization consists in compressing the ozonized air and forcing it up through towers down which the water is passing.

FIXATION OF NITROGEN*

The most important use of the high tension electric arc is in the so-called fixation of atmospheric nitrogen.

Nitrogen for Fertilizers. Nitrogen is the most important element which gives value to our principal fertilizers. The increasing demand for such fertilizers and the approaching exhaustion of the great deposits of sodium nitrate and other natural nitrogen compounds make the problem of the future supply of great importance. The atmosphere contains a free and inexhaustible supply of this element, but in this form it is not directly useful because it is not "fixed", that is, in combination with other elements which appear to be essential for its usefulness in the growing of crops.

It has long been known that where a high tension discharge takes place, there is a partial union of the oxygen and nitrogen of the air to form the chemical compound NO.

Following the design and operation of a great many types of apparatus, it was found advisable to avoid short thick arcs and to employ long thin stable arcs which would come in contact with a large quantity of air. Units of large capacity in consuming much energy have been worked out.

Birkeland-Eyde Process. An electric furnace devised by Birkeland and Eyde has achieved a notable success in the fixation of nitrogen of the air. In this furnace a large surface of contact of air and arc is attained. The principle is illustrated in Fig. 46. Two water-cooled copper electrodes are brought within a distance of one inch or less and are connected through an inductive resistance to a source of alternating pressure of 5000 volts. The high tension arc which is first produced quickly breaks down to a low voltage arc carrying a heavy current. This low voltage arc is avoided by an ingenious method of placing the poles of a powerful electromagnet at either side of the arc, Fig. 47. It is well known that a conductor located in a magnetic field and carrying a current tends to move out of that field. The electric arc follows this law and tends to move upward or downward, depending upon the direction of the current. In moving away from the straight line connecting the two ends of the electrodes, it becomes lengthened and this lengthening tends to maintain the arc as a high tension arc and avoids the low tension form. In moving away and lengthening, the resistance increases, the current falls off, but the voltage increases because of the

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* An exhaustive treatise on the utilization of atmospheric nitrogen is published by the Department of Commerce and Labor, under the authorship of Thomas H. Norton.

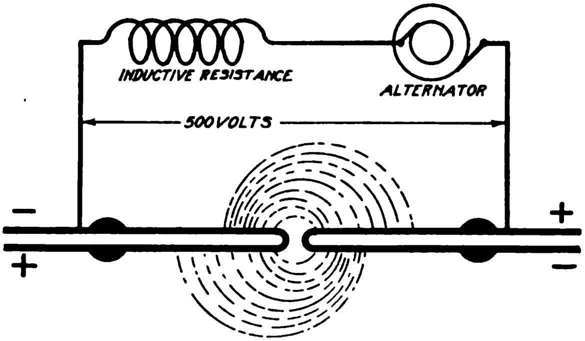


Fig. 46. Diagram of the Electric Circuit in the Birkeland-Eyde Electric Furnace

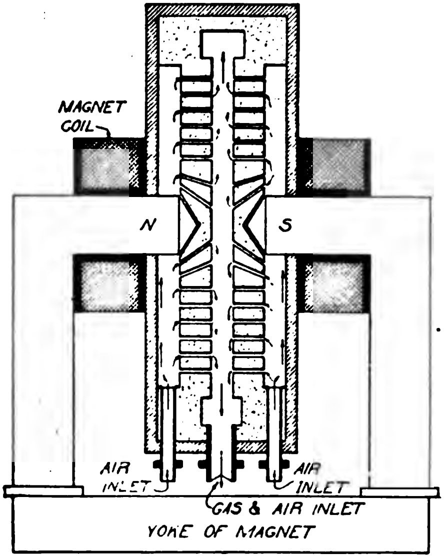


Fig. 47. Birkeland-Eyde Furnace

lower voltage drop through the inductive resistance. The arc is finally drawn to such a length that it breaks and a new arc is then established and goes through the same process. By using an alternating current, the arc formed by one-half of the alternating-current wave travels upward from the electrode and on the reversal of the current an arc is formed which travels downward, and these arcs are formed at the rate of fifty per second, in accordance with the frequency of the current used. On account of this high frequency it is impossible to detect each separate arc and in looking into the furnace what is seen is apparently a large disk sheet of light. The air is introduced so that it travels parallel with this disk and is, therefore, fully exposed to the action of the discharge.

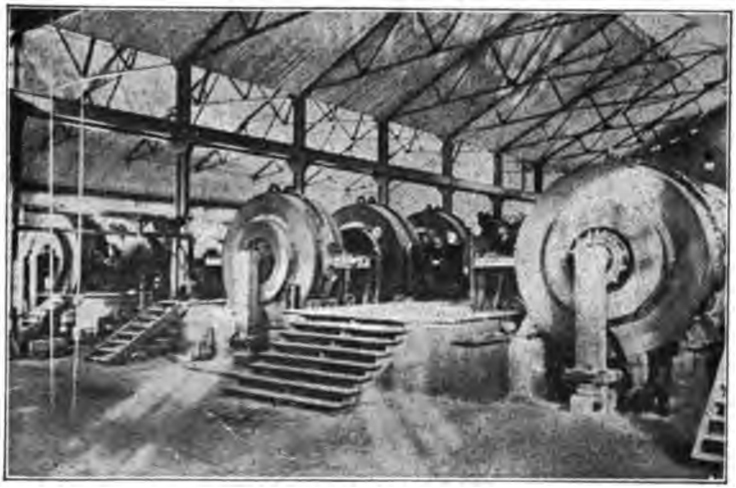


Fig. 48. Birkeland-Eyde Furnaces at Notodden

It is estimated that the temperature of the disk is about 2300° C. The furnace is of steel, lined with fire-bricks which are perforated by holes through which the air enters.

Units of 750 kw. have been employed, such units requiring a pressure of 5000 volts. The full sized units in operation are illustrated in Fig. 48.

ELECTRICAL FUME PRECIPITATION

Another important application of high tension currents is in the removal of suspended particles of solid or liquid materials from

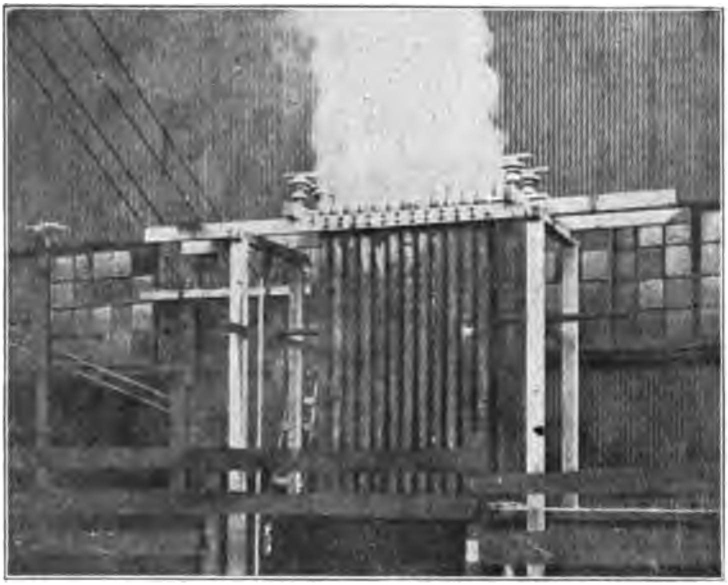


Fig. 49. Experimental Tubular Treater Before Application of Current. Fumes in the Center Above Apparatus

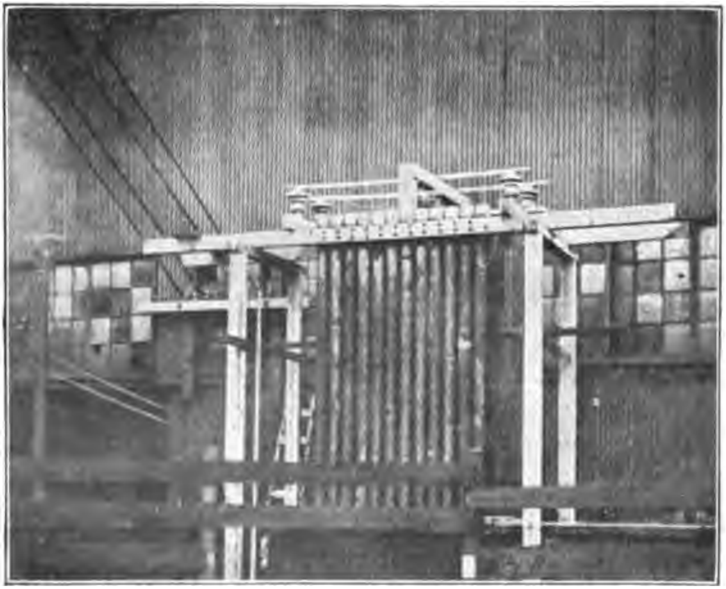


Fig. 50. Tubular Treater After Current Has Been Turned On, Showing Dissipation of Fumes

gases. It has long been known that the fine particles constituting fog, dust, and fume, may be quickly settled by passing between two electrodes at which a high pressure is maintained. There is an agglomerating effect on the suspended particles which causes them to produce larger bodies which settle by gravity. When direct pressures are employed, there is an actual attraction between the electrodes and the agglomerated particles, which increases the rate of settling or collection.

Recovery of Valuable Products of Combustion. This phenomenon has a commercial application in the settling of valuable materials which are carried in furnace gases, not only to render these gases less objectionable to the surrounding territory, but also to recover valuable materials which would otherwise be lost. It also looks promising in connection with the smoke problem. There are likewise innumerable instances in industrial work where the separation of solid and liquid particles from the air can be advantageously effected by this method.

Cottrell Process. The commercial practicability of this action of high tension currents has been demonstrated recently in the work of Dr. Cottrell and the United States Bureau of Mines. In the apparatus used, an economic and effective source of high tension direct current is obtained by transforming the ordinary alternating current up to 20,000 to 30,000 volts and then rectifying this pressure to an intermittent direct current by means of a rotary contact maker, driven by a synchronous motor. This high tension direct current is applied to a system of electrodes in the flue, which carries the gases to be treated. Numerous practical forms and arrangements of electrodes have been developed to meet the exacting and varied conditions of large scale operation in different installations.

The effect of turning on the current to an experimental apparatus used in connection with a copper converter is shown in Figs. 49 and 50.

WELDING LIGHT SHEET-METAL TANKS AND CONTAINERS BY THE OXWELD PROCESS

This view is taken in the plant of one of the largest makers of such articles in the United States
The gas-welding process has been found to produce better results in quicker
time and with more economy than any other method

Courtesy of Oxweld Acetylene Company

PART II

WELDING

INTRODUCTION

Welding an Ancient Art. The art of joining metals is one of the oldest known to man. Ever since the first cave dweller or half-monkey man hammered his first piece of iron or copper between two stones, the development of the art has gone forward, and will probably continue to develop so long as men use metals. The welding of iron is apparently as old as the production of that metal by man, for there is, in a temple yard of the ancient city of Delhi, India, an iron pillar nearly two thousand years old, which shows unmistakable evidences of having been welded. The shaft projects 22 feet above the surface of the ground, extends over 40 feet into the earth, and is about 16 inches in diameter. It was apparently welded into one piece from blooms which weigh about 70 pounds each; the joints are as perfect as could be made with our most modern equipment, and yet they were forged by hand.

Conditions for Successful Welding. Strictly speaking, "welding" is the uniting or joining of two pieces of metal by hammering them together while they are hot enough to be plastic, and the application of the term would thereby be limited almost entirely to work done in a blacksmith shop. But modern methods of obtaining high temperatures by gases and electricity have made possible the development of other and better methods of joining metals, many of which cannot be welded by hammering. Custom has applied the term "welding" to these also, although some of them are really brazed or soldered with metals of high melting temperatures. Any process by which cohesion between the molecules of the pieces to be joined is brought about may be called "welding".

Metals are most easily welded when in that degree of plasticity between the molten and the solid states; hence, those metals which remain plastic the longest while cooling are the easiest to weld. Originally, welding was limited to such metals as iron, platinum, nickel, and gold, but the recent development of high temperature systems has extended the field greatly. In fact, it is safe to say that every metal may be welded by some one or other of the modern methods. So recently as five years ago it was considered impossible to weld aluminum; but this is being done successfully today with the electric-arc system, using the graphite electrode, and practically every kind of alloy is also being welded by both the electric-arc and the gas systems.

Successful welding by any method depends almost entirely upon three factors: flow, cohesion, and temperature. The metal must tend to flow under great pressure, even if but to a slight degree. The surfaces of the pieces to be welded must tend to "wet" each other or cohere to an appreciable extent. The working temperature must be that at which the foregoing conditions are most prominent. The best welding condition for iron and steel exists within a limited range of temperature only and, when in this condition and at this temperature, they possess the property of expanding when cooled and contracting when heated. Therefore, modern welding systems are designed to take advantage of these well-known laws in the best and most economical manner, or else they are not considered commercially desirable and will, therefore, soon be abandoned.

It is for the purpose of describing in a general way these systems and their applications that this book has been compiled and it is our desire that all students of the art of welding may profit to the highest degree through their study of this subject. The field is expanding rapidly and great financial gains should be possible to the well informed during the next few years.

METALS AND THEIR NATURES

Iron and steel are the most useful and the most used metals we have and, since steel is merely iron with the addition of a small percentage of carbon and a few other elements, we will consider iron first.

Iron. Iron is made by taking iron ore, placing it in a furnace with fuel (coal, coke, or charcoal) and a suitable flux (usually limestone), and then melting it with the assistance of a forced draft until the ferrite in the ore is reduced to metallic iron. This is then run out into molds to form the "pig iron" of commerce. If this pig iron is again melted in a cupola and cast into molds of various shapes, it is called "cast iron" and is the material so largely used now for machinery and other articles.

Cast Iron. Cast iron is hard and brittle and granular in composition, because it contains so much carbon. This latter substance has come from the fuel used in melting the iron and the carbon content can be varied to suit requirements by "burning" it out. This is done by forcing a strong blast of heated air through the iron while it is still molten, causing the oxygen in the air to combine with the carbon and carry it off in the form of carbonic-acid gas, ($C\,O_2$). Charcoal makes the best fuel for use in smelting because it is so free from sulphur and other impurities and it is used when making so-called Swedish iron. Good charcoal iron is easily welded and will stand more bending without breaking than any other kind of iron. Wrought iron is almost entirely free from carbon and is very malleable and ductile, hence easily welded.

Steel. Steel is wrought iron with an appreciable percentage of carbon added, the amount depending upon the use to which it is to be put. It is made by simply stopping the air blast when making iron and leaving a small amount of carbon in the metal. This is usually at the point where the mixture still possesses the ductility and malleability of wrought iron together with the hardness and brittleness due to the carbon. This is why steel is both tough and hard and the amount of carbon determines the hardness. While wrought iron is slightly fibrous, steel is crystalline, but it may be improved by working at the proper temperature, and good steel is homogeneous throughout.

Soft Steel. Soft steel, or "mild" steel, as it is called commercially, contains very little carbon and is really on the dividing line between iron and steel. When it is made by forcing air through the molten iron to burn out the carbon, as previously described, it is called "Bessemer" steel, after the inventor of the process. The desired amount of carbon is afterwards supplied by adding an iron called "spiegeleisen" which contains both carbon and manganese, the latter enabling the iron to hold a larger amount of carbon and adding to its strength.

Open-Hearth Steel. Open-hearth steel is made by melting cast iron in an "open hearth" or broad shallow furnace and adding the proper proportions of scrap wrought iron or steel and iron ore. This is a very tough steel and is used for boiler plates and similar articles.

Per Cent of Carbon in Steel. In all of the processes the steel is cast into ingots and then rolled or forged into bars, sheets, or other shapes for commercial purposes. The amounts of carbon in iron and steel are approximately as follows

Cast Iron	3. % to 4.5%
Tool Steel	.5% to 2 %
Mild Steel	.1% to .5%
Wrought Iron	Less than .1%

Steel Castings. Steel castings are usually made of mild steel and contain small amounts of manganese, silicon, sulphur, and phosphorus in addition to the carbon. Manganese and silicon improve the steel but sulphur and phosphorus are not desirable. Aluminum is also added sometimes as a solidifier or deoxidizer before pouring the castings and it improves their quality. The amounts of these elements in steel castings usually vary as follows

Carbon	.18% to .75%
Manganese	.30% to .80%
Silicon	.27% to .33%
Sulphur	.032% to .056%
Phosphorus	.032% to .092%
Aluminum	Traces only after melting

Steel Alloys. The various elements used to alloy iron are technically known as "impurities", even though their addition is a distinct advantage. All of the alloys of iron and steel may be welded by any of the modern methods, although some of them cannot be welded by the blacksmith. *Silicon* causes brittleness and too much of it prevents welding, on account of the crystalline structure of the alloy, but the addition of manganese tends to overcome this and make it more weldable.

Manganese up to 1.5 per cent may be added to iron or steel without preventing welding, but more than that makes a brittle alloy. Manganese reduces both the sulphur and oxygen in the iron and adds greatly to its strength. *Nickel steel* may be welded and the addition of nickel up to 5 per cent is safe, if the amount of carbon is kept small. Nickel increases the tensile strength of steel without impairing the elasticity and also tends to prevent rusting of the iron alloy. *Chrome steel* may also be welded successfully.

Copper. Copper is one of the elemental metals and is found as an ore and in a pure state. The ore must be smelted and the copper refined before it is ready for use in the arts like other metals. It is cast and sold in the form of ingots and should be at least 99.5 per cent pure and entirely free from sulphur. It is used largely in the form of sheets, bars, and tubes and occasionally it is cast in molds like iron and steel.

It is the principal element in brass, bronze, gun metal, and many other alloys, and is nearly as useful to man as iron. It can be welded readily by any method, although this is rarely done, for brazing and soldering have been the processes generally used for joining or repairing pieces of it. Great care must be exercised when casting copper to insure its being properly deoxidized and the same thing applies to welding it. Silicon, aluminum, and phosphorus are used for this purpose, although aluminum alone presents the disadvantage of oxidizing rapidly when exposed to the air.

Bronze. Tin and copper form a good alloy called "bronze", which is harder than either metal alone. The addition of tin increases the fluidity of copper but diminishes its ductility; the strength of copper is increased by adding up to 12 per cent of tin, and its crushing strength is increased by additions up to 18 per cent of tin. Beyond this latter point the bronze becomes hard and brittle. "Gun metal" is copper with from 8 per cent to 2 per cent of tin but the best alloy contains about 10 per cent of tin. Great care must be used when welding alloys containing tin because the latter melts at a comparatively low temperature and may easily be burned when welding.

Brass. Zinc and copper form the alloy known as "brass", and percentages of zinc as high as 40 per cent are sometimes used without serious effect on the malleability or ductility of the alloy but more zinc makes it very brittle. Tin is sometimes added to brass to increase its strength. Zinc is a good deoxidizing agent for copper but it vaporizes quite rapidly at high temperatures. This causes the zinc to pass out of the alloy, leaving the copper porous or spongy; this is why brass is so hard to weld satisfactorily. Lead is also used as an alloy for copper but not over 3 per cent can be used because it does not mix well.

Manganese Bronze. Manganese is alloyed with copper in various proportions for certain purposes. This alloy is known as "manganese bronze" and may be both forged and welded by proper methods, although welding is a rather hard process to perform satisfactorily with it. The ductility and strength are both very high and the alloy does not corrode easily, even in salt water. It weakens slightly when heated and shrinks more than gun metal; hence it requires special care during welding operations.

Phosphor Bronze. Phosphorus is also used with copper for making bearing metals and makes a strong alloy which resists corrosion. The percentage of phosphorus used when making "phosphor-bronze" castings ranges from 2 per cent down to but a few hundredths of one per cent; frequently the phosphorus causes hard spots because it does not always combine freely and thoroughly. This alloy is also hard to weld readily, although it may be done by proper methods.

Aluminum. Aluminum is the lightest of the commercial metals and is very valuable for forming alloys but it is rather hard to weld or solder because of the rapidity with which it oxidizes, especially at high temperatures. Castings of aluminum are being successfully welded now, however, by several methods; and sheets of aluminum are welded by the gas methods. The various alloys are also being welded; the heat conductivity is comparatively high and it acts like solder when melted; it melts at 655 degrees centigrade; it is easily burned; and a sort of scum forms on the surface, if welded with a high-oxygen flame.

Commercial welding is confined almost entirely to the metals here described, although gold, silver, platinum, and a few others are weldable and are used in some of the finer arts. The characteristics of iron, steel, and copper, however, are most important to remember in connection with commercial welding and manufacturing.

WELDING PROCESSES

Classification. While it is true that there are many variations of the principal processes of welding and joining metals, they may safely be placed in one of four general classes: smith or forge welding, electric welding, gas or hot-flame welding, and chemical welding. Included with these are such allied operations as soldering, brazing, and riveting for joining metals; so some reference will also be made to them, although the latter cannot be considered as welding in any sense of the term. Riveting is treated of here because it is one of the processes being superseded by the modern welding systems for some classes of manufacture, and the student should have some knowledge of the process and its relative value.

Smith Welding. Smith welding, or forging, is the general process of forming or joining metals by hammering or pressing the pieces into the desired shape and may be done either hot or cold, depending upon circumstances. When joining two or more pieces of metal, especially iron or steel, it is done hot and is one of the oldest of the useful arts. It is the most common of all of the welding processes but depends more upon the skill of the operator than any other process of welding; hence it is gradually being superseded by them. It is also rather expensive and slow and is not so suitable for large or heavy work as some of the other systems.

Electric Welding. Electric welding has been used as a laboratory process for a number of years but has recently been developed commercially to such an extent that it is rapidly coming to the front as the most important of all of the welding processes. Five different systems have been developed for using electrically generated heat for welding purposes, each of which has been named in honor of the inventor. These are the Thomson, Zerener, Benardos, Slavianoff, and LaGrange-Hoho systems, of which the Thomson has two forms, viz., "butt welding" and "spot welding," the names indicating the kinds of joint formed.

The *Thomson system* requires the use of alternating current whereas the other systems use direct current for welding. The Thomson system and its latter day modifications consist in bringing together the two pieces to be welded, in a special machine, passing an alternating current through the point of contact until the parts are heated sufficiently to be soft and then squeezing them together until they unite. The heating is due to the resistance of the joint to the passing of the current before the parts are soft enough to weld.

The *LaGrange-Hoho system* is also based on resistance and consists in placing the pieces of metal in a bath of electrolyte, causing the current to flow to them from a positive electrode and heating them until soft enough to weld. The actual weld is made by hammering, the same as smith welding; so this is not at present a very important process commercially.

The three other processes use the electric arc as the source of heat, and do their work by filling in additional material to join the pieces. The *Zerener system* is based upon using two pieces of carbon in a suitable holder, causing the arc or flame to be deflected toward the work by means of a magnetic field and using the arc to melt the filling material. The *Benardos system* consists in using a piece of carbon or graphite as one electrode for the arc, drawing the arc between the carbon and the work (which is the other electrode) and using the heat of the arc to melt the filling material required for joining the pieces.

The *Slavianoff system* also consists in drawing an arc between the work and an electrode, but a piece of the filling material is used as one of the electrodes and melts directly into place on the job. This is the most important of the electric welding processes, although it is the most recently developed to a commercially practical point. It is applicable to practically every class of welding and for nearly all metals, and is the simplest of all welding processes. It will probably be in universal use within a very few years.

Gas Welding. Gas welding, or hot-flame welding, is at present next in importance to smith welding and is applicable to many kinds of work which cannot be done by forging. The three most important processes commercially are known as the *Oxy-acetylene, Oxy-hydrogen,* and *Blau-gas processes.* All of these processes consist in using oxygen and another gas to give a flame of sufficiently high temperature and heating capacity to melt the material to be welded, the gas used with the oxygen being indicated by the name of the process. In all cases the oxygen and other gas are mixed in a suitable burner and the flame directed on the work in such a way as to cause the metals to flow together and, when no extra material is added to form the weld, it is said to be "autogenous" or self-forming. Electric-arc welding is also autogenous to the same extent, although the term is not strictly correct. The details of these systems will be described later.

Chemical Welding. Chemical welding is exemplified today almost exclusively by the process known as "thermit welding" and consists in igniting a mixture of oxide of iron and aluminum so as to set up a chemical reaction which evolves an intense heat. This is done by placing the mixture in a suitable mold and igniting, causing the aluminum to reduce the iron from its oxide, thus evolving the heat required and forming what is called "thermit-steel". The molten steel is allowed to run out of the mold and into and around the part to be welded, thus forming a "cast-weld" of considerable strength. A suitable mold must also be formed about the part worked upon in order to retain the metal until cooled; so this process is comparatively slow and expensive. Several other chemical processes have been developed but as they are not of very great importance commercially at this time, they will not be described here.

Brazing and Soldering. Brazing and soldering are processes which approach welding so closely in some of their applications that they are worthy of serious consideration as a part of that subject. *Brazing* consists in joining metal by fusing a filling material called "spelter" into the joint by heating, first preparing the surfaces of the joint with a suitable flux. When brass is brazed, it really becomes a welding process because brass is the principal constituent of spelter. The heat is produced by a gas flame and the work is done at a comparatively high temperature.

Soldering, or "metallic gluing", as it has been called, is done by melting a soft alloy into the space between the parts to be joined. It can be done with a gas flame or a heated soldering copper and at comparatively low temperatures. Soldering is a comparatively old process, is cheap, easily learned, and in wide use, but it should not be used for any joint requiring much strength. It is not suitable for joints in iron or steel or in several of the alloys.

Riveting. Riveting consists in joining plates, sheets, or other shapes of metals by means of small pieces of metal which pass through the parts and are headed over on both sides. This process is also old and will be described in detail later in order to bring out the comparison between this and the newer methods of joining materials.

Miscellaneous Processes. Several other processes of joining metals are being advocated by their inventors, among which may be mentioned the "Ferrofix brazing process" and the "Laffitte welding plate", although neither of them is in very extended use at present. *Ferrofix brazing* consists in cementing together two pieces of iron by means of a thin film of brass in such a way that the brass alloys with the iron and forms a joint that is stronger than the iron.

The necessary heat is supplied by a gas flame of suitable temperature. *Laffitte welding plate* consists of a special chemical preparation molded over a sheet of wire gauze and it is used by placing the plate between the surfaces to be welded. The parts are heated to a cherry red, the plate inserted, and the pressure applied while the reaction takes place. The preparation of the plate is such that it supplies the flux, the reagent, and the filling material and makes a joint of relatively high strength. Both of these processes have been introduced into the United States but recently and their relative values have still to be determined; they will be described in detail later.

SMITH WELDING OR FORGING

Smith welding is the process of joining metals by laying the pieces together and hammering at the place of contact until they become one piece. Most metals must be heated nearly to the temperature at which they begin to flow, before they can be welded. For iron and steel this is at the white heat; so let us first consider the action of the fire and the equipment required before taking up the study of the process in detail.

Producing the Proper Temperature. The combustion of fuel, either coal, coke, oil, or charcoal, causes the oxygen of the air to combine with the carbon of the fuel, and this chemical combination is what produces the heat. The *amount* of heat produced depends upon the amount of carbon and oxygen combined during combustion; whereas, the *temperature* attained depends entirely upon the rapidity with which the combination takes place. This is one of the most important facts to be learned in connection with welding, because the principle involved applies to all of the other systems of welding as well as to smith welding.

Forced Draft. Ordinarily, combustion would not be rapid enough to generate the amount of heat required for welding; so a draft is created through the fire in order to supply enough oxygen to the fuel and increase the rate of combustion. Too much air will chill the fire or blow it out, and an excess of oxygen will cause some of it to combine with the iron and form a scale of oxide of iron. This is called an "oxidizing fire"; whereas, if the oxygen is all consumed in the fire and there is an excess of carbon, it is then called a "reducing fire".

Fuels. Coal, coke, charcoal, oil, and gas are all used as fuels for forges, but charcoal is the best because it is almost free from impurities. Coal and coke are good unless they contain sulphur and phosphorus. Sulphur makes iron "hot-short", or brittle when hot, and phosphorus makes it "cold-short", or brittle when cold. Copper, lead, tin, and other non-ferrous metals should be kept out of the forge as they will spoil iron for welding.

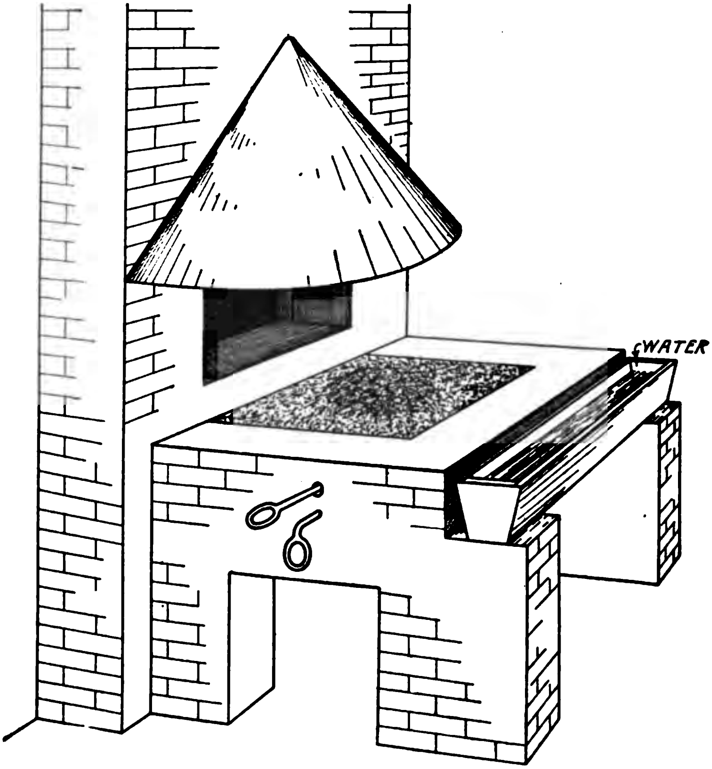


Fig. 1. Brick Blacksmithing Forge

Forges. Forges are of various kinds, usually of brick or iron, Figs. 1 and 2, and consist primarily of a bowl with an air inlet or "tuyere" in the center of the bottom, a hood overhead to carry smoke and fumes to the chimney, a blower or bellows to supply air, an ash pit, and a trough or other vessel for water. Usually a blast of air at a pressure of from 4 to 6 ounces per square inch should be maintained. A type of portable forge is shown in Fig. 3.

Forging Tools. *Anvil.* An anvil is required to provide a surface upon which to lay the pieces, when hammering to make the weld. It may be of cast steel or of wrought iron with a steel face, and usually weighs from 150 to 200 pounds. The anvil should be placed on a block of hard wood, Fig. 4, and securely fastened to it, and the height should be such that a man's knuckles will just reach to the top of it when he stands alongside.

Hammers. Hammers and sledges of various sizes and styles are required. Hand hammers, Figs. 5, 6, 7, and 8 weigh from 1 to 2½ pounds and have handles from 14 to 16 inches long. Hand sledges, Fig. 9, weigh from 5 to 8 pounds and have handles from 24 to 30 inches in length. They are handled by a helper. Swing sledges, Fig. 10, weigh from 8 to 20 pounds and have 36-inch handles. They are used for heavy work only and the helper strikes a blow with a free full-arm swing.

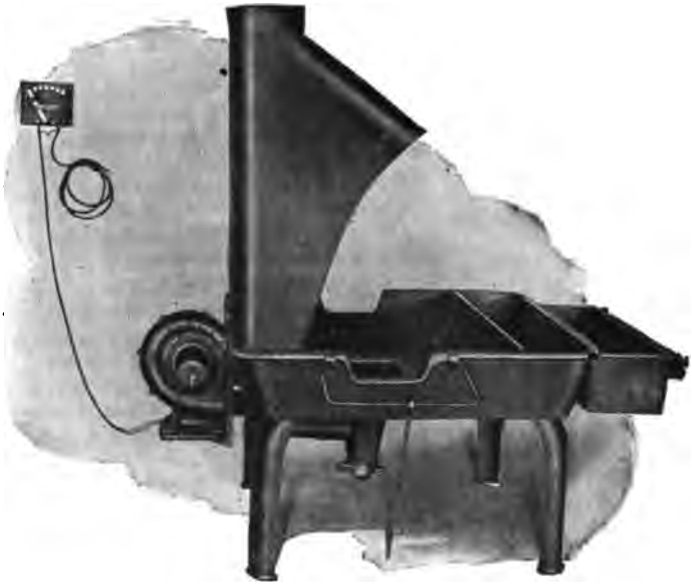


Fig. 2. Modern Motor-Driven Forge
Courtesy of Canedy-Otto Company

Ball-peen, or chipping, hammers, Fig. 7, have a round top or ball-shaped peen on the head. The striking face is flat, but the peen head is used for riveting or for stretching metal by hammering. Cross-peen hammers, Fig. 8, have a long ridge running across the

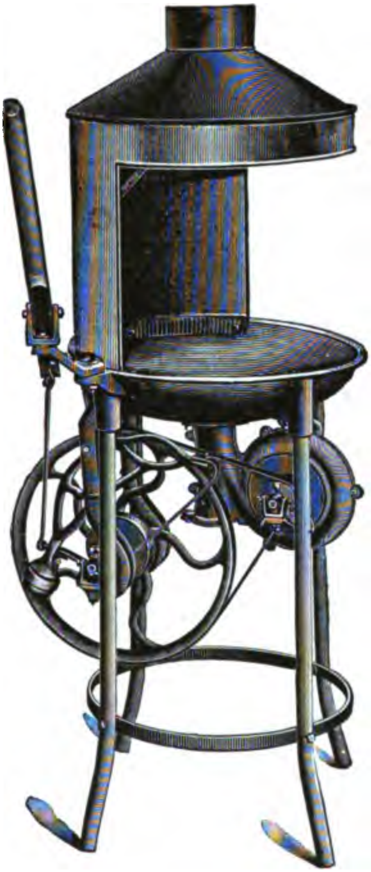


Fig. 3. Portable Hand Forge
Courtesy of Canedy-Otto Company

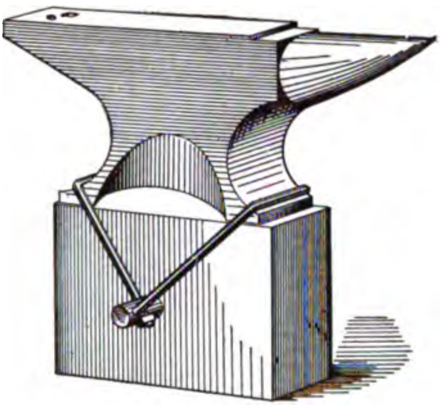


Fig. 4. Anvil Fastened to Block

top of the head and are used when stretching metal lengthwise and for riveting. Straight-peen hammers, Fig. 5, have a ridge running lengthwise of the head and are used when the metal is to be spread sidewise. Hammers should be selected to suit the work to be done and the strength of the user, and they should be of the best quality.

In addition to the foregoing hammers for general use, there are

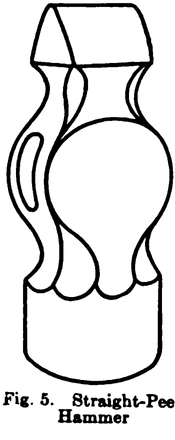


Fig. 5. Straight-Peen Hammer

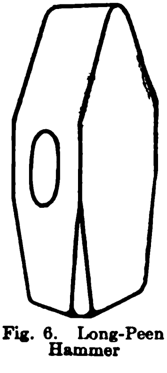


Fig. 6. Long-Peen Hammer

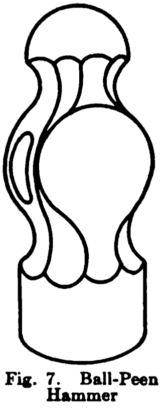


Fig. 7. Ball-Peen Hammer

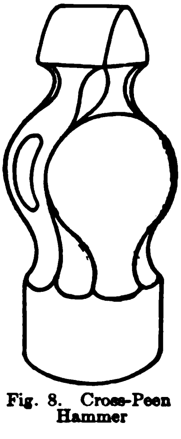


Fig. 8. Cross-Peen Hammer

various kinds for special purposes. These include "set" hammers of various shapes, for forming the iron. Square set hammers, Fig. 11, are for producing flat surfaces; flatters, Fig. 12, are for similar use but cover a wider area; fullers, Fig. 13, are for spreading out the iron, hollowing out work, and forming shoulders; swages, Fig. 14, are for rounding pieces of iron and are of numerous sizes; punches, Figs. 15 and 16, are for making holes and are made square and round; and cutters, Figs. 17 and 18, are hammers with chisel-like edges on the top of the head for cutting bars, etc.

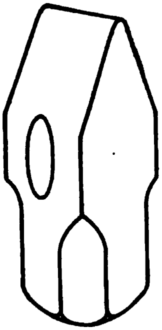


Fig. 9. Hand Sledge

Anvil Tools. Anvil tools with stems to fit the square "hardie" hole in the anvil are made in shapes to match the set hammers previously described. They include fullers, swages, hardies, heading tools, etc., Figs. 19 and 20.

Tongs. Tongs are of many kinds and special ones are easily made when peculiar pieces are to be worked. Flat tongs, Fig. 21, are used for flat iron bars, strips, or plates. Pick-up tongs, Fig. 22, have curved springy jaws and are used for handling small pieces. Bolt tongs, Fig. 23, have a sort of pocket in the head or jaws for holding bolts while forming them. Gad tongs, Fig. 24, are shaped somewhat like bolt tongs except that the nose of the jaws is flattened somewhat like flat tongs. They are used for holding

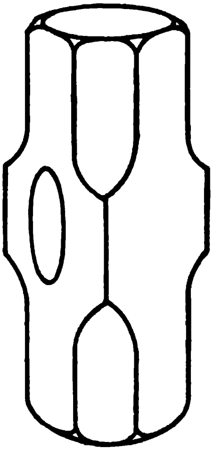


Fig. 10. Swing Sledge

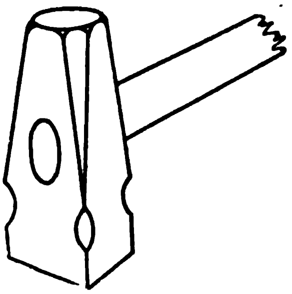


Fig. 11. Square Set Hammer

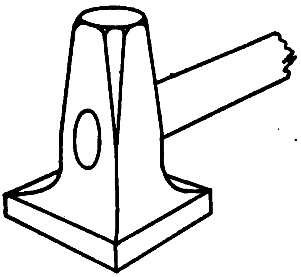


Fig. 12. Flatter

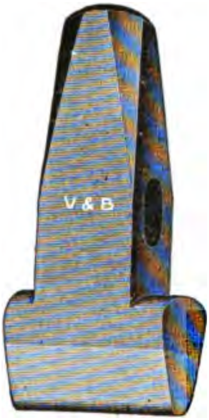


Fig. 13. Fuller

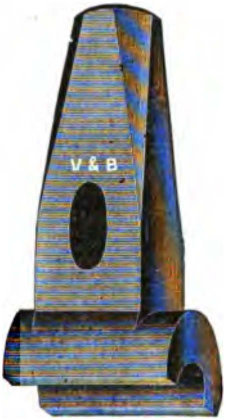
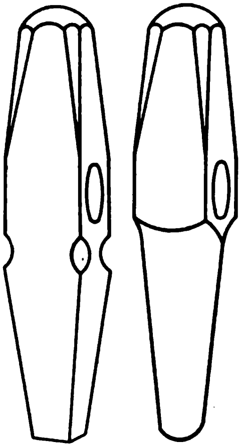


Fig. 14. Swage

Courtesy of Vaughan and Bushnell Manufacturing Company

flat pieces which are thick at one end or side. Tongs soon become spoiled by the constant dipping in water and they bend out of shape easily while hot. They should not be left in the fire unless necessary and should be kept in a rack when not in use.

Miscellaneous Equipment. In addition to the foregoing essential equipment, smith shops frequently contain many other tools such as dies, swage blocks, vises, surface plates, gages, taps, dies, calipers, Figs. 25 and 26, etc. For handling the fire there should be provided a poker, fire hook, shovel, sprinkler, and ladle, Figs. 27 and 28. A monkey wrench, chisel, and a pair of "C" clamps are also useful, and a tapered mandrel will be needed if rings are to be welded. A large portion of the equipment here mentioned will also be required for welding by any other method and a well-equipped shop is generally a good investment. On the other hand, it is usually better to start with the smallest equipment which will do the general run of the work and then buy special tools and equipment which experience shows to be necessary.



Figs. 15 and 16. Square and Round Punches

Figs. 17 and 18. Cold and Hot Cutters

Courtesy of Vaughan and Bushnell Manufacturing Company.

General Features of Smith Welding. The process of smith welding, or forging, is comparatively easy to learn, but skill and the ability to use the process successfully will only come after long practice. The first operation to learn is to heat the iron properly; this is done by placing it in the fire until it reaches a bright red, almost white, color. Large pieces will take longer to heat, and will remain hot longer, than small ones and the surface will tend to oxidize and flake off upon exposure to the air while hot. For ordinary forging operations this is no disadvantage beyond reducing the size of the piece slightly but, when welding two pieces together, this oxide

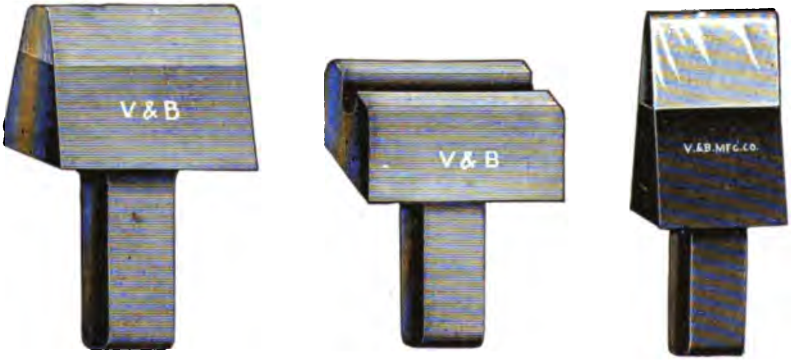


Fig. 19. Bottom Fuller and Swage and Hot Hardie
Courtesy of Vaughan and Bushnell Manufacturing Company

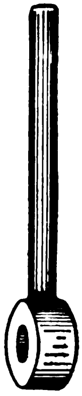


Fig. 20. Heading Tool

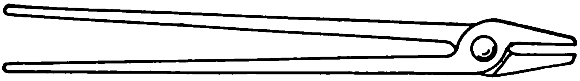


Fig. 21. Flat Tongs

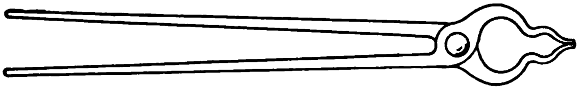


Fig. 22. Pick-Up Tongs

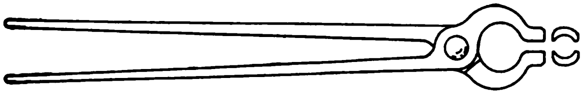


Fig. 23. Bolt Tongs

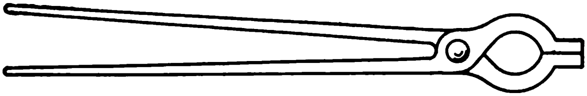


Fig. 24. Gad Tongs

must be kept off by the use of a good flux or it will destroy the value of the weld by preventing cohesion of the particles forming the pieces. The most common flux for iron is clean sharp sand because it will fuse and stick to the surface and keep out the air; but work can be done without a flux, if it is done quickly. For steel, it is better to use potter's clay, wet with strong brine and then dried and powdered. Borax is sometimes used but it is not good for the metal.

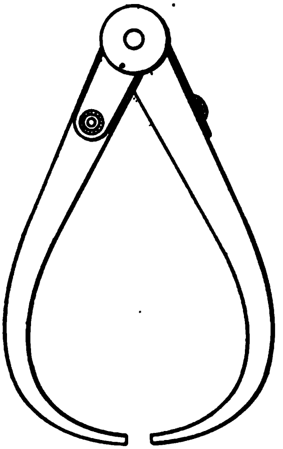


Fig. 25. Outside Calipers

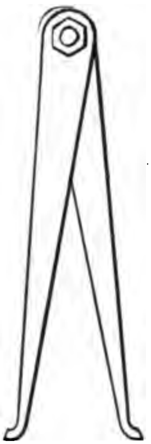


Fig. 26. Inside Calipers

Simpler Operations Performed First. The simpler operations of forging should be learned first and then the welding tried afterwards. "Drawing" is the operation of stretching the iron in one or two directions and it consists in hammering the hot piece on all sides for lengthening or on one side for flattening or spreading. If the piece tends to curl, it can be hammered on both sides to keep it

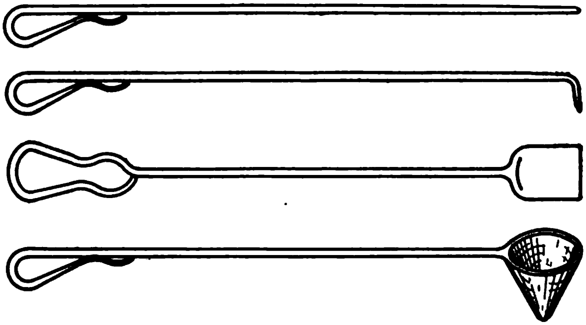


Fig. 27. Types of Fire Handling Tools

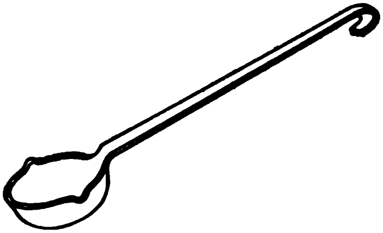


Fig. 28. Ladle

flat. Square pieces should be turned over and over and hammered on all sides in drawing, and round ones should be hammered on all sides. "Upsetting" is the operation of increasing the diameter or thickness of a piece by heating and then hammering it on the ends until it becomes shorter through the flowing of the metal to the heated portion. The bar usually tends to bend under this operation; so it should be straightened at once by hammering on the high side. Considerable heat is required for upsetting and the fibers tend to separate or split apart, when the piece is hammered lengthwise of its grain; so it is well to finish the upsetting by heating again and hammering all around to weld the fibers again. Bolt heads are formed by upsetting the bar on the end and hammering square, or hexagonal, as required.

When forming corners which must be square, the pieces must first be upset to get enough stock and, when making connecting rod straps, crank shafts, rocker arms, hook eyes, eyebolts, axe heads, armature shafts, and other articles of variable thicknesses, it is customary to upset them from straight bars before beginning to shape them. After the student has practiced the more elementary operations described and becomes familiar with his tools and his metal, he can then try welding.

Kinds of Welds. There are several kinds of joints made by smith welding, each of them being known by a name which indicates the manner in which the pieces are joined. These are the "scarf weld", "butt weld", "lap weld", and "cleft weld", and the proper one to use will depend upon the shape of the piece and the strains it will meet in service.

Scarf Weld. The scarf weld, Fig. 29, is made by "scarfing", or thinning the pieces at the end, in order to give them a bevel; the iron should be upset a little to give enough extra stock to allow for the drawing down when hammering. The pieces should be rounded slightly on the surfaces which come together in order to allow the scale and slag to squeeze out and then they should be hammered while at a white heat. When they are thoroughly joined, the piece should be shaped all around by turning while hammering.

Butt Weld. A butt weld consists in hammering two pieces end to end until they unite, the pieces being rounded slightly on the ends, Fig. 30, to allow the scale to come out. This operation will tend to

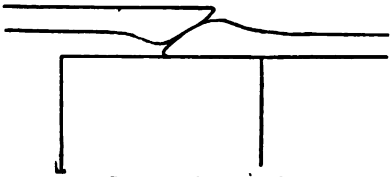


Fig. 29. Scarf Weld

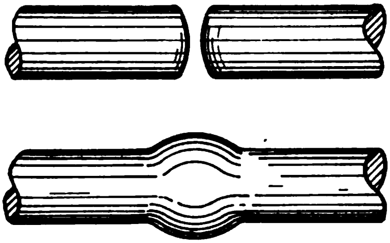


Fig. 30. Butt Weld

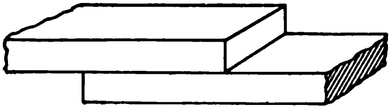


Fig. 31. Lap Weld

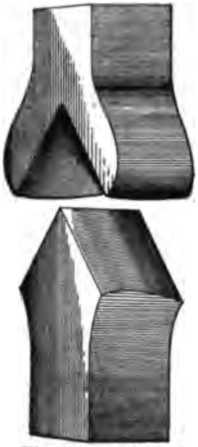


Fig. 32. Cleft Weld

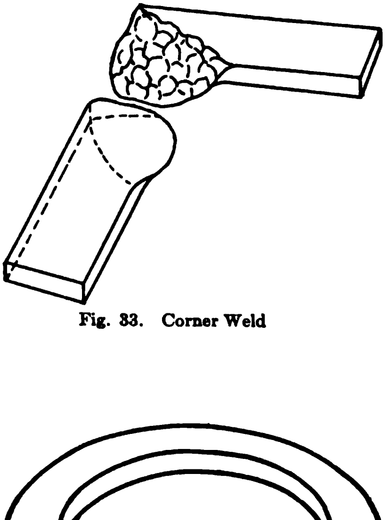


Fig. 33. Corner Weld

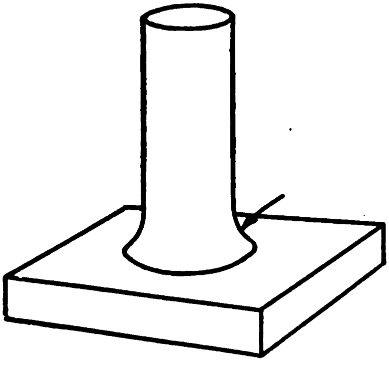


Fig. 34. Jump Weld

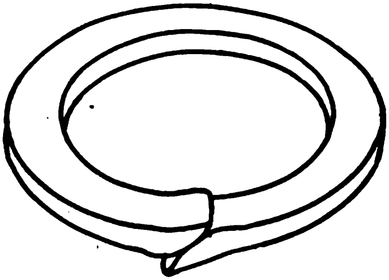


Fig. 35. Ring Weld

upset the pieces and they should be drawn down to size again after welding. This sort of a joint is not so strong as a good scarfed joint.

Lap Weld. A lap weld, Fig. 31, is made by simply laying one piece on top of the other and hammering until they unite. Work should start at the center and proceed toward the outside in order to force out the slag; otherwise the metal will not unite. It is not necessary to round up the parts for this joint, but a better job is insured if it is done.

Cleft Weld. A cleft weld, Fig. 32, makes the strongest joint and consists in splitting one piece at the end, tapering the other piece, and slipping it into the fork of the first piece; then, by hammering the sides of the cleft together, the pieces are made to unite. The pieces should be first hammered on the ends in order to drive them tight together in the cleft, and it is good to round the sides of both pieces on the welding surfaces to allow slag to flow out.

Applications of Smith Welding. The applications of smith welding are numerous, but a few of them will serve to give an idea of the possibilities. Scarf welds are used to form the corners of frame work made of flat bars, Fig. 33, and one piece is beveled on the end and the other on the side and the joint is made as previously described. Jump welds, Fig. 34, are also made by scarfing the pieces in the same way and welding; and rings, Fig. 35, are made by scarfing the ends of the strip and welding. To determine the length of a piece for making a ring, add the thickness of the stock to the inside diameter of the ring and multiply by $3\frac{1}{7}$. For straight pieces to be welded, add the thickness, or diameter, to the length to allow for the joint.

Butt welds are used, when joining heavy pieces—especially pieces of irregular shape that are to be upset first—and for lengthening pieces of large cross section, such as shafting. Lap welds are used for comparatively thin sections like steel tires, hoops, and plates, and sometimes for making tanks and large piping. Tubes are sometimes lengthened by swaging one part large enough to slip over the other and then lap-welding them by hammering with a mandrel inside to prevent distortion, and to give something to act as the anvil to hammer against. Cleft welds are used when welding steel to iron, as, for instance, putting hard tips on picks, attaching tool steel drills to soft shanks, etc., and for work requiring great strength of joint, such as tie-rods for bridges. Borax should not be used as a flux for this purpose, unless it has first been calcined or melted in a ladle, cooled, and powdered in order to remove all moisture from it. When making a weld between iron and steel, it is best to heat them both at once; dip the iron in sand and the steel in borax; reheat the iron white and the steel cherry red; and then weld with a heavy hammer. After they are joined, they should be reheated and then finish with a lighter hammer. Steel facing is another welding operation and consists in welding a piece of steel flatwise against the iron to give it a hard surface; it is used in making some kinds of tools.

SOLDERING AND BRAZING

Both the soldering and brazing processes are similar to welding in so far as they are methods of uniting metals, but they are different in that the filling or joining material is usually of different composition from the pieces joined. The work of brazing brass and soldering lead resembles the welding process without the hammering but it is not welding in the proper sense of the term; it is, rather, a sort of "metallic gluing" process.

Soldering

Soldering is the process of joining pieces of metal by filling the space between them with material known as "solder", and doing it in such a way that the solder will adhere to both of them and hold them together. The first requirement of a good solder is that it will "wet" the surfaces, or amalgamate with the pieces to be joined. Alloys of lead and tin, with the addition at times of other metals, are the usual solders, although special solders are made without either of them. Soldered joints are not so strong as welded or brazed joints because of the material used but they are frequently used because they are easily and cheaply made.

The process requires less heat than welding or brazing and the joints may be cooled rapidly. An ordinary gas flame with a foot pump for the blast, or even a candle and a blowpipe, may be used for soldering. If the piece worked upon is so large that it rapidly conducts away the heat, a gasoline or kerosene torch is used to preheat the piece and prevent chilling the solder. The blowpipe is used for small work like jewelry and the only point to watch is to be sure the flame is hot enough to burn all of its carbon. The blue center of a flame is highly oxidizing whereas the yellow outside portion causes a reducing action.

Fluxes. Fluxes are essential to successful soldering and there are several kinds on the market, although most operators soon learn to make their own. The fluxing materials generally used are salammoniac zinc-chloride solution, rosin in alcohol, borax, and tallow. Flux is used to dissolve grease and to remove any oxide present after cleaning. It combines chemically with the oxide and leaves a clean surface of metal which the solder will wet. Sometimes the flux is combined with the solder when making up the sticks, and this is known as "self-fluxing" solder.

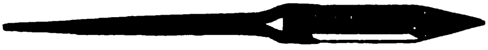


Fig. 36. Soldering Copper
Courtesy of Central Electric Company

Tools. The tools required for soldering are very simple and few in number. The source of heat for the operation is usually a soldering "copper" or "bit," Fig. 36, which has in turn been heated in a gas or charcoal stove, Figs. 37, 38, and 39. It is made with a comparatively large head, small shaft, and wooden handle and has a pointed tip on the head for working. The tip should be "tinned" before using, and this is done by first cleaning and sandpapering, fluxing with zinc chloride, and heating. While hot it is rubbed well with a stick of tin which adheres to the surface, and it will remain tinned for a long time unless heated to a red heat. A type of grooved soldering copper is shown in Fig. 40, and an electric soldering tool is shown in Fig. 41.

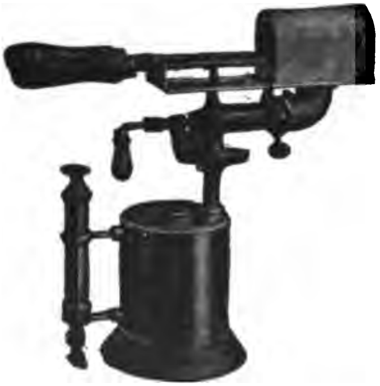


Fig. 37. Soldering Iron Heating Stove
Courtesy of Central Electric Company

Solders. Most solders melt at about 200 degrees centigrade (392° F.), the softer solders melting at about 180 degrees centigrade (356° F.) and harder solders at about 330 degrees centigrade (626° F.).

There are so many special solders on the market that no closer figures can be given, but these will be a safe guide for most of the ordinary kinds of work. Ordinary solder is half tin and half lead. Hard solder is two parts lead and one part tin. Antimony is sometimes added to harden and stiffen solder, and arsenic is added to make it flow more freely. Bismuth makes the solder brittle and cadmium makes it soft. When bismuth and cadmium are both added they reduce the melting point, and "Wood's metal", which contains two

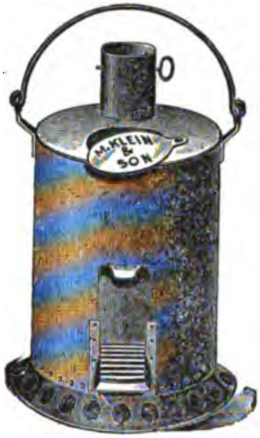


Fig. 38. Charcoal Stove
Courtesy of M. Klein and Son

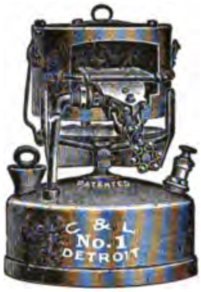


Fig. 39. Gasoline Furnace
Courtesy of Central Electric Company

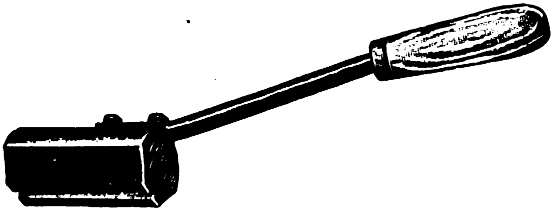


Fig. 40. Grooved Soldering Copper
Courtesy of Central Electric Company

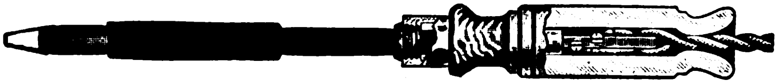


Fig. 41. Electric Soldering Tool
Courtesy of Central Electric Company

parts of tin, two of lead, two of cadmium, and eight of bismuth, melts at 70 degrees centigrade (158° F.). Copper strengthens solder but raises the melting point very rapidly.

Soldering Process. The process of soldering consists in first scraping the surfaces clean; heating the pieces to the soldering temperature by any suitable means; fluxing the surfaces to be joined; applying the solder with the solder bit; and finishing the joint by smoothing off. Rust and grease must be scraped or washed off with some alkaline solution. With liquid fluxes it is best to apply them after heating the surfaces to be joined, in order to eat away the film of oxide and keep the surface clean but, with borax or rosin solutions, it is best to apply them cold. After the surfaces are properly cleaned, heated, and fluxed, the solder is melted on with a flame or by rubbing with a hot bit and then the joint is smoothed up.

The most important points to watch are the temperature and the flux. Too much heat causes oxidation, makes the solder run too freely, and burns the tinning off the soldering tips. Poor fluxing prevents the solder from amalgamating with the pieces and, hence, they will not join. Platinum, silver, gold, tinned sheet iron, and most other metals may be soldered but it has thus far been practically impossible to solder aluminum commercially. A number of processes have been devised for soldering aluminum but none of them are in very general use and most of them have been failures.

Brazing

Brazing is a process similar to soldering, the main difference being in the use of a harder filling material and one requiring a higher melting temperature. Gold, silver, copper, brass, and iron may be brazed and the process consists broadly in melting a filling material called "spelter" into the joint to be made. The spelter used for brazing varies with the nature of the work, the hard alloys consisting of copper and zinc, and the soft ones consisting of tin and copper, or tin and antimony. Hard spelter gives a stronger joint than soft spelter, of course, but in all cases the spelter must amalgamate with the metal joined in order to make a good joint.

Flux. The flux for brazing is made of borax or boracic acid, the latter being cheaper. Borax will swell up under the flame, blister, and run off unless the water of crystallization has been burned out, whereas good borax will melt and run over the surface and clean it nicely. The surfaces should be cleaned carefully before brazing, the same as when soldering. Salammoniac, zinc chloride, salt, and various acids have been tried as brazing fluxes but none are so good as borax.

Equipment. The equipment required for brazing consists principally in having suitable means for heating the pieces to the proper temperature and a supply of the proper spelter. Beyond this there are many good things which assist in making brazing easier, such as special fixtures for holding the pieces while working, torches or furnaces of various sizes, and similar things which will suggest themselves to the worker from time to time. As stated, the things which are necessary are but few in number.

A torch is used when brazing small and moderate-sized pieces and a forge or furnace such as shown in Fig. 42, for heating large pieces. Gasoline or kerosene give more heat than gas, but a blacksmith's forge provides the best means for heating and cooling. The pieces to be brazed should be preheated, brazed, and cooled slowly, and care must be taken to see that any sulphur in the coal or any soot from the fire is kept away from the pieces to be welded. The parts should not touch the fuel. A reducing or nonoxidizing flame is required and the brazing is done at a high temperature. Iron and steel require almost a white heat and a Bunsen flame with a blue cone is generally used.

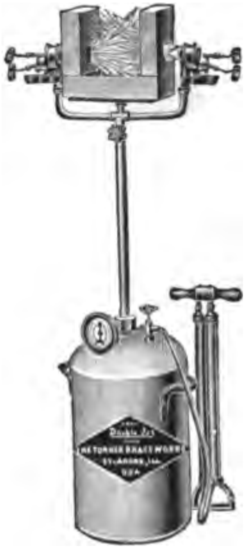


Fig. 42. Double-Jet Brazer
Courtesy of Turner Brass Works

Process of Brazing. The process of brazing varies according to the work to be done and is a somewhat more expensive and complex process than soldering. The surfaces to be brazed must be cleaned, of course, by scraping and washing, and then brushing with a wire brush. The borax or other flux is then applied and the pieces placed together ready for brazing. The tighter the parts are clamped, the stronger will be the joint. If no regular furnace is available, a rough one should be build of bricks, Fig. 43, so as to enclose the articles on all sides but one, in order to retain the heat.

There is considerable variation in the practice of brazing, for the details of the operation depend upon the nature of the work to be done, the size and the shape of the pieces, the material, etc. For the production of pieces in quantities, especially articles made of sheet metal, the spelter is melted in a ladle or pot and the pieces are dipped therein. In this operation the flux is floated on top of the spelter and the pieces are cleaned before dipping. The flux then does its work as the articles are dipped into the spelter.

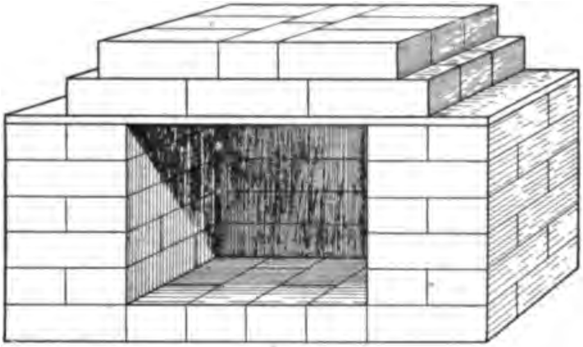


Fig. 43. Temporary Brick Furnace for Brazing

For castings and other articles which require brazing, but which cannot be dipped because of the nature or location of the joint, it is customary to prepare the joint as previously described; place the pieces together in proper position; build a temporary furnace around the piece, or place it in a suitable furnace; and then heat it by playing a flame on it. Gas torches with air blast, Fig. 44, make good heaters and the temperature may be regulated to suit the size

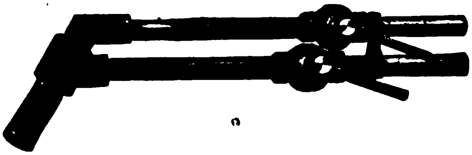


Fig. 44. Hand Gas Torch for Brazing
Courtesy of Turner Brass Works

of the piece. When the article is properly heated and fluxed, the spelter will flow into the space between the parts, wet both surfaces fully, and make a tight joint.

Care should be taken to see that the article does not cool too quickly, especially iron castings, or unequal shrinkage will cause cracking. Heating should also be gradual to prevent unequal expansion for the same reason and burning must be avoided. Sometimes the pieces may be covered with graphite paint, except where the brazing is to be done, thus preventing the flame affecting those parts. This is especially important when brazing brass as it should prevent the zinc from volatilizing and passing out of the alloy, thus leaving it spongy. The brazing of gold and silver requires special alloys; this is usually put in the hands of a jeweler and, as it is generally a small job, it is usually done with a blowpipe.

Use of Brazed Joints. Brazed joints are often stronger than the original metal but are not so good as welded joints, although they are cheaper and easier to make. Cast-iron pieces will not break at the joint, when properly brazed, and such joints are about 15 per cent stronger than the casting. One of the greatest objections lies in the possibility of leaving flux or rust in a brazed joint and weakening it. There is also danger of electrolytic action between the spelter and the material brazed and brazed joints do not always stand up well under repeated shocks. On the other hand, on articles of steel there are probably more joints made by brazing than by any other process (except riveting), thus proving it to be a generally reliable commercial process.

RIVETING

Riveting is not a welding process but it deserves a place in any treatise on the art of joining metals because it is in such general use for that purpose. While it is true that riveting is rapidly being superseded in many cases by various welding processes, it will never be abandoned entirely and is therefore worthy of consideration here.

Details of Process. The process of riveting consists in joining pieces of metal by means of rivets, which are short pieces of soft bars or rods with a head on one end. They are usually made of the same material as the pieces to be joined, such as steel, iron, copper, brass, aluminum, etc., and are used hot or cold as may be required. Steel and iron rivets for joining plates or other pieces of the same materials are usually red-hot when used; so they are easier to head over and will draw the pieces tightly together as they shrink while cooling. Rivets of softer materials are used cold.

Shapes of Rivet Heads. The more common forms of rivet heads are shown in Fig. 45, wherein *A* shows a plain round head on both sides of the plates; *B* shows a round head on both ends but with the plates slightly countersunk to form a shoulder under the head for added strength; *C* shows a plain rivet with a pointed or steeple head above and a rose, or cone, head below; *D* shows a countersunk head above and a round head below; *E* is similar to *D* with the lower plate countersunk to give a shoulder under the head, and *F* has countersunk heads both above and below. Round heads are most commonly used; steeple and cone heads are used for boilers; and countersunk heads are used only when necessary for finish or to avoid some other attachment.

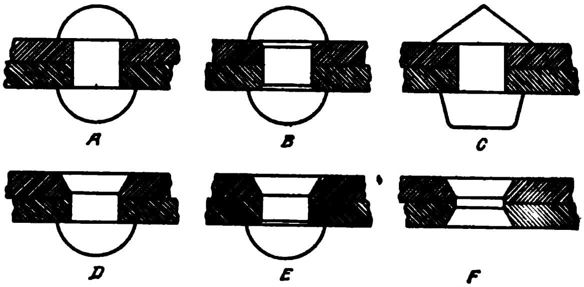


Fig. 45. Types of Rivet Heads

Tank and Boiler Work. When making tanks, pipes, boilers, or other articles of steel plates, the first operation is to shear the plates to the desired size and then trim the edges. Rivet holes are then punched or drilled near the edges of the plates, these being of the proper size and quantity for the strength demanded. If the article to be made is cylindrical in form—such as a boiler—the plates must be bent to the proper shape by being passed through rolls after the rivet holes are made. A few bolts should be put into some of the holes, after the plates have been placed in proper position for riveting, in order to hold the plates in place until the rivets have been driven and set. These can then be removed and rivets substituted for them. Rivets always used to be headed over by hand but machine riveting has been adopted now for nearly all work done in shops and a large part of that done in the field; it is much to be preferred on account of its uniformity.

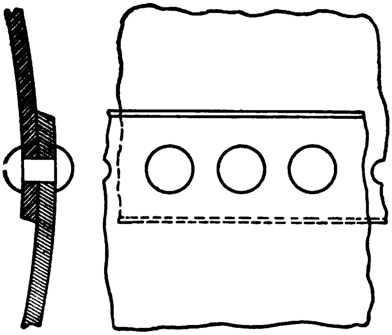


Fig. 46. Single-Riveted Lap Joint

Types of Joints. The joints used in riveting plates are either of the lap or of the butt type; a lap joint is one where the plates are laid on top of each other, and a butt joint is one where the plates come together edge to edge with another plate covering the joint. The added plate is known variously as a "welt strip", "cover plate", or "butt strap"; two of them are used for extra heavy work. Where the plates lap over and a single row of rivets is used, the joint is known as a "single-riveted lap joint", Fig. 46, this being the commonest and most used form of joint and being entirely suitable for the majority of seams. Where the plates lap further and two rows of rivets are used, as in Fig. 47, it is called a "double-riveted lap joint", this type being used for moderately heavy plates or for high pressures. If the plates are brought together edge to edge and a cover plate put on one side as in Fig. 48, it is known as a "butt joint with a single strap" and is frequently used for the lengthwise seams of tanks or boilers. For very high pressures and heavy plates the custom

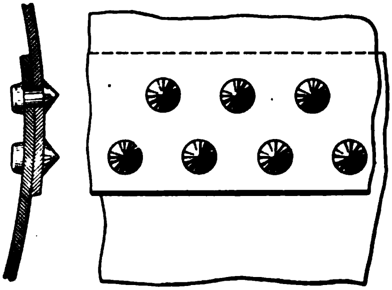


Fig. 47. Double-Riveted Lap Joint

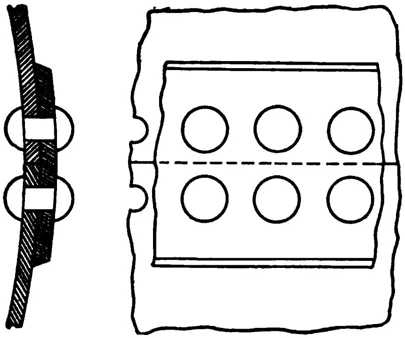


Fig. 48. Butt Joint with Single Strap

is to use a "butt joint with two welt strips", two rows or three rows of rivets being used through both plates and strips, and an additional row passing through the inner strip and plates only, Fig. 49. Other types of joints are sometimes used but these are the most common and most easily made. When a single butt strap is used, it is about 1⅛ times the thickness of the plates but when two are used, the outer one is of the same thickness as the plate and the inner one is about ¾ the thickness of the plate. Butt joints should be used for plates over ½ inch thick, two strips being used. Wherever longitudinal and girth seams meet, the plates should "break joints," as shown in Fig. 50, rather than be continuous. The inside lap is made to face downward so as not to form a ledge for the collection of sediment.

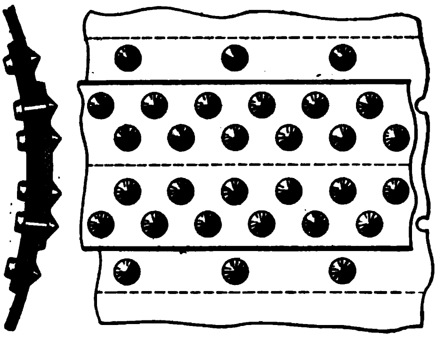


Fig. 49. Butt Joint with Two Welt Strips

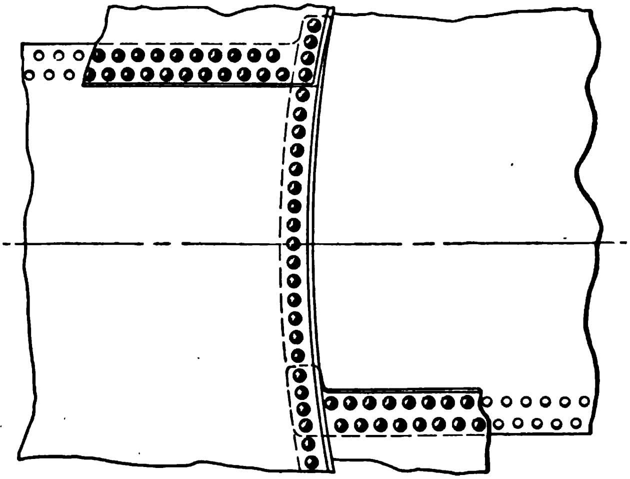


Fig. 50. Typical Boiler Shell Showing Method of Riveting and Breaking Joints

Strength of Joints. The strength of a riveted joint depends upon the materials used, the diameter and numbers of rivets, and the way in which the strain is applied to the rivets. The plate may break along the line of the rivet holes; or the rivet itself may shear off; or the plate may shear out in front of the rivet or it may simply crush in front of the rivet. Rivets should never be used where they are subjected to a tensile or pulling strain as their greatest strength is when in shear or crosswise strain. If they can be placed in double shear through using butt joints and butt straps on both sides, they work still better. Plates seldom shear in front of the rivets but sometimes they break along the line of the rivets and rivets sometimes shear off or pull out under heavy strains.

Table I gives the figures used by several boiler and tank makers for riveted joints and applies to single-strap butt joints and lap joints. The "efficiency of joint" indicates the relative strength of the joint and the rest of the plate, and is given as a ratio. The "pitch" indicates the distance between the centers of the rivet holes in the plate.

TABLE I

Efficiency of Single-Strap Butt Joints and Lap Joints

THICKNESS OF PLATE, INCHES	DIAMETER OF RIVET, INCHES	DIAMETER OF HOLE, INCHES	PITCH		EFFICIENCY OF JOINT	
			Single, Inches	Double, Inches	Single	Double
$\frac{1}{4}$	$\frac{5}{8}$	$\frac{11}{16}$	2	3	.66	.77
$\frac{5}{16}$	$\frac{11}{16}$	$\frac{3}{4}$	$2\frac{1}{16}$	$3\frac{1}{8}$	.64	.76
$\frac{3}{8}$	$\frac{3}{4}$	$\frac{13}{16}$	$2\frac{1}{8}$	$3\frac{1}{4}$	.62	.75
$\frac{7}{16}$	$\frac{13}{16}$	$\frac{7}{8}$	$2\frac{3}{16}$	$3\frac{3}{8}$	.60	.74
$\frac{1}{2}$	$\frac{7}{8}$	$\frac{15}{16}$	$2\frac{1}{4}$	$3\frac{1}{2}$	.58	.73

When laying out plates and riveting, care should be taken to see that the various longitudinal seams do not come in line with each other, but that they are offset, or staggered. The inner plate of the longitudinal seam should be hammered thin at the edge where it comes to the circumferential or girth seam so that the rivets can draw the plates tightly together at all points; otherwise there will be leakage.

When rolling iron and steel plates, there is a fiber formed lengthwise of the plates in the direction they are rolled and, when making boilers or tanks, it is important that this fiber should run around the boiler in the direction of the girth seams to get the greatest strength. When ordering plates, it is customary to give that dimension first which indicates the way the fiber must run. When plates are to be flanged or turned up around the edge, as for heads of tanks or boilers, the curve at the corner should have a radius equal to at least four times the thickness of the plate and the material should be of the best quality. Marine boilers sometimes have the edges of the shell flanged inward and a flat plate used for the head, but this method is more expensive than flanging the head for most work.

Calking. Calking is the operation of closing the edges of a riveted joint to make the plates fit tight and give a good joint. A round-edged tool, Fig. 51, is driven against the edge of the overlapping plate so as to make it flow down against the other plate and close up any space between them at the edge. Unless this operation is properly done, however, the seam may be opened instead of closed and the joint be made worse than before, and this is one of the operations that is being superseded by electric welding. Electrical calking is done by using a metallic electrode and depositing metal along the edges of the plates by means of the heat from an arc, thus covering the joint and drawing the two plates together, Fig. 81.

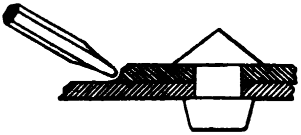


Fig. 51. Calking a Riveted Seam

Riveting Tools. The tools required for riveting consist of hammers, calking tools, rivet sets for forming the heads, rivet heating furnaces, punches, shears, drills, drifts for drawing the holes in line, and, in some cases, pneumatic or hydraulic riveting machines. For the average small shop it will be sufficient to have hammers, heaters, shears, punches, and drifts, with a set or two for the heads. The use of drift pins for drawing the holes in line is very common practice on cheap work but should never be done on a good job as it distorts the holes and prevents the rivets from filling them. Punched holes should not be used for good work as this operation is liable to injure the plates. Drilling is preferable, especially for steel plates.

ELECTRIC-ARC WELDING AND CUTTING

Historical. The use of the electric arc as the source of heat for joining and melting metals is one of the oldest applications of electricity and yet it was not developed to a commercially practical point until within a comparatively few years. In 1786, Martinus van Marum published a book, in Leipzig, describing some early electrical experiments, and, in this book, he gave an exhaustive treatise on the melting of metals by means of the electric current. In 1810, Sir Humphrey Davy, the versatile English scientist, described some experiments made in London with various metallic bodies, and, in 1815, J. G. Children of Londen described a process for welding iron wire with the electric arc obtained from batteries. From then until now, the development of the art of electric welding has progressed steadily, so that today it stands as the most universal of all welding systems and is being adopted rapidly for all classes of metal manufacture and repair. The men who have done most to perfect electric-arc-welding processes are De Meritens, Bernardos, Olszewsky, Coffin, Zerener, Slavianoff, Howard, and a few others of lesser importance, and further reference to the processes developed by some of them will be made.

Characteristics of the Electric Arc. The electric arc has probably been given more careful study and investigation than any other electrical phenomenon and yet there is comparatively little exact knowledge available regarding some of its most important characteristics. The exact temperature of an arc has never been determined although the most refractory substances may be melted in its vapor and, since the vapor is so hot, it is a very efficient source of heat. The temperature has been variously estimated at from 2000 degrees centigrade by some scientists up to 6000 degrees centigrade by others, but the temperature generally accepted as correct is about 4000 degrees centigrade. As long ago as the year 1840, Grove discovered that the current flows more easily from metal to carbon than in the reverse direction and that the current through an arc is greater, when passing from an easily oxidized metal to one that is not, than when flowing in the reverse direction.

The explanation of this is comparatively simple. The conductivity of an arc depends largely upon the kind of vapor in the arc and, to some extent, upon the ease with which the cathode (negative electrode) can be kept at a high temperature. If the anode (positive electrode) gives off a conducting vapor when heated, this vapor will help the conductivity of the arc. In the arc-welding systems in commercial use today, the arc is drawn between metal and carbon, or between metal and metal and, since the positive electrode or terminal of an arc reaches a higher temperature than the negative electrode, it is more efficient to use the article worked upon as the positive electrode of the arc. Since iron is more easily vaporized than carbon, the current flows more easily from iron to carbon than the reverse, because there is more iron vapor than

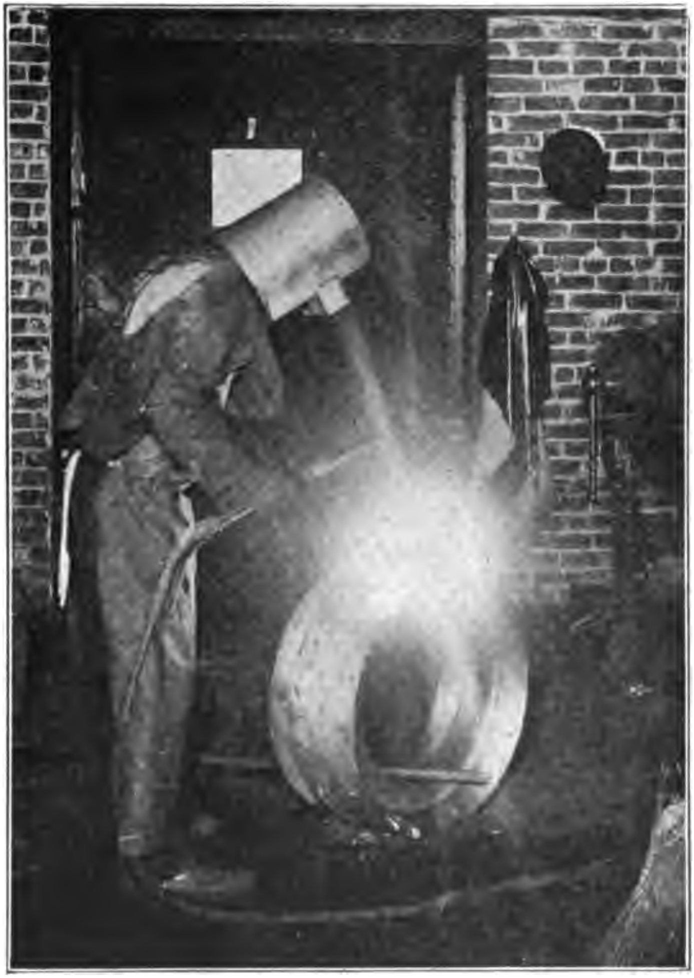


Fig. 52. "Striking the Arc"
Courtesy of Westinghouse Electric and Manufacturing Company

carbon vapor in the arc. This is proved by the fact that it requires more voltage to send a given current through an arc between carbon electrodes than between iron ones. It is also important that the negative electrode be kept at a high temperature and the usual practice of having the negative electrode small (due to the use of a wire or carbon pencil) makes this easily possible.

ELECTRIC WELDING PROCESSES

General Features. The process of welding or cutting with the electric arc is possible with nothing more than a source of current at a suitable voltage, some means for regulating the amount of current flowing, and an electrode. Practice has shown, however, that certain other devices are necessary, if satisfactory welding is to be done; and it is the determining of these devices and their proper uses that constitutes the main differences in the various processes used today. In order to do welding or cutting with the arc it is necessary first to connect the work to the positive side of the power-supply circuit and the electrode to the negative side of the circuit, by means of wires or cables, and to insert a regulating resistance in either of these circuits to limit the current flowing to the proper amount. The negative electrode should then be placed in contact with the work and quickly withdrawn, thus establishing the arc, Fig. 52, which provides the temperature required. As the metal soon begins to melt the work may begin at once.

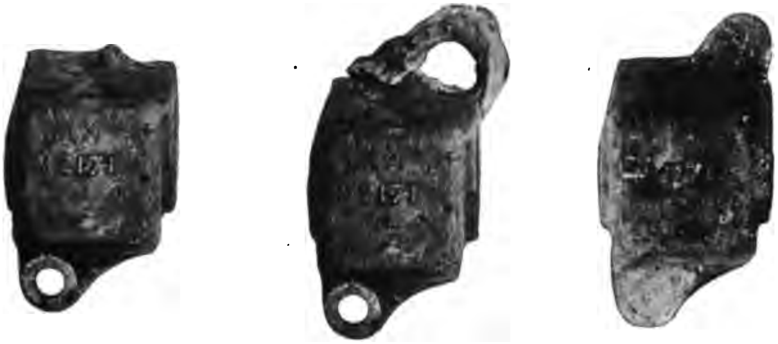


Fig. 53. Arc-Welding Lug on Steel Casting
Courtesy of Westinghouse Electric and Manufacturing Company

In general, electric-arc welding consists in using the heat of the arc to fuse or melt the filling material into the place to be filled,

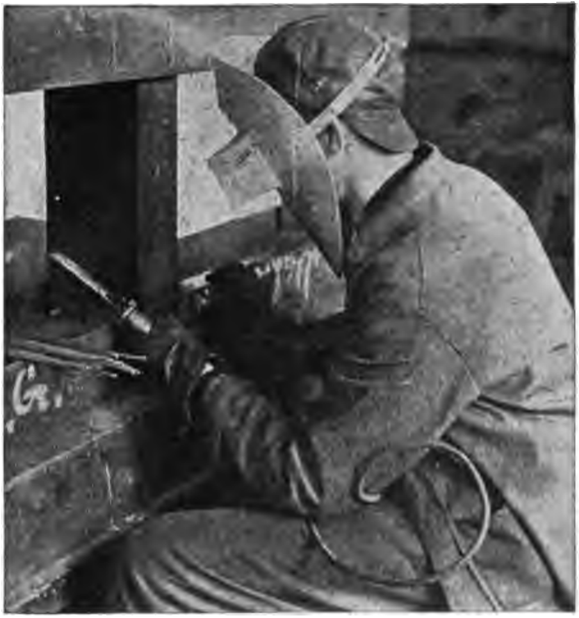


Fig. 54. Operator Using Metallic Electrode
Courtesy of C & C Electric and Manufacturing Company

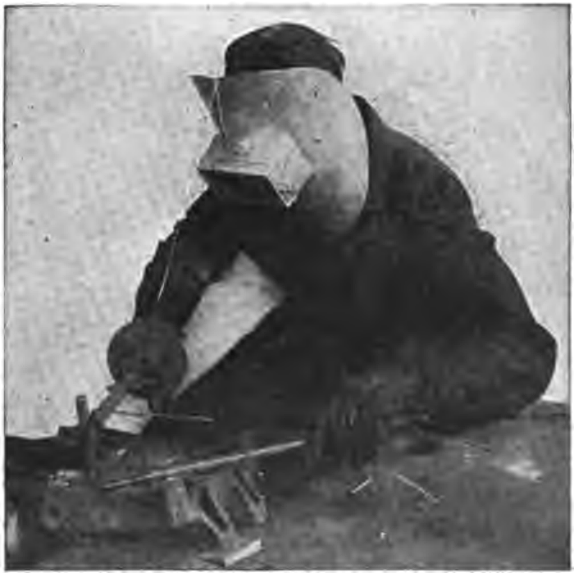


Fig. 55. Operator Using Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

Fig. 53, although the article worked upon may be melted down sufficiently to fill the space, if it is large enough at the point to be welded. Two methods or processes of using the arc for welding are in commercial use today, these being the "metallic" and the "graphite" processes. The metallic welding process, Fig. 54, consists in using a piece of wire as the negative electrode of the arc and fusing it into place; the graphite process, Fig. 55, consists in using a piece of carbon or graphite as the negative electrode and fusing a piece of metal into place by the heat of the arc, similar to a gas process. The graphite process is always used for cutting, a slot being melted through the piece to be separated. There is also a third system which will be described later, but it is not used much in the United States.

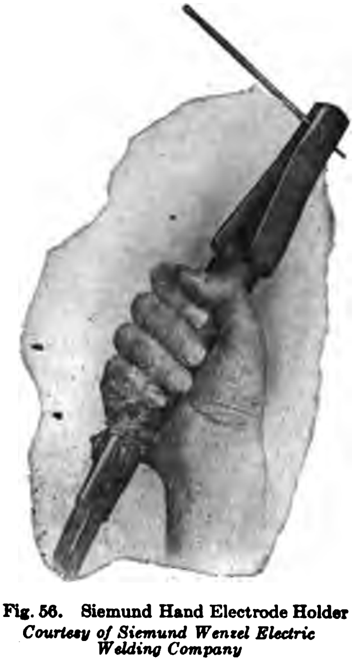


Fig. 56. Siemund Hand Electrode Holder
Courtesy of Siemund Wenzel Electric Welding Company

Benardos System. The Benardos system of electric-arc welding is based upon the use of a carbon pencil as the negative electrode and the article worked upon as the positive electrode, using for the purpose a continuous, or direct, current at a moderate voltage (usually from 60 to 70 volts). After the arc is established by touching the electrodes together and withdrawing, a piece of the filling material in the form of a "melt bar" is fused into place by the heat of the arc. Any metal, which does not volatilize or burn up too easily at the temperature obtained, may be welded by the Benardos process and this process is the best to use for cast iron, the copper alloys, and aluminum. When using the graphite pencil, it is necessary to give the hand a sort of rotary motion in order to cause the arc to play about over the surface of the job and prevent burning, for the arc never stops melting the metal so long as it exists. This motion also has the effect of causing any slag or impurities on top of the molten mass to flow off to one side, instead of remaining in the weld and spoiling its quality, and of distributing the heat more uniformly over the piece welded. When cutting with the arc, the article should be so placed that work can begin at the top and progress downward across the face of the piece.

Slavianoff System. The Slavianoff system of electric-arc welding is based upon the use of a metallic pencil, Fig. 56, as the negative electrode, and the article worked on as the positive electrode, and the use of a continuous current at low voltage. After the arc has been established by touching the electrodes together and separating them, as before, the negative electrode itself begins to melt and thus forms the filling material. This system is more successful for work with iron and steel electrodes than with the other metals, although many of them may be used where high-class work is unnecessary. The main application of this system has been to sheet-steel work, the metal electrode being deposited along the joint to be made and tying the two plates together so that they form practically one piece. This process may also be used for building up worn or missing pieces, filling holes, etc. The current required for the Slavianoff process is much less than that for the Benardos process but it is much slower for operations involving the placing of any very large amounts of metal quickly. The successful development of the Slavianoff system has been the principal cause for the recent rapid spread of electric-arc welding in the industries.

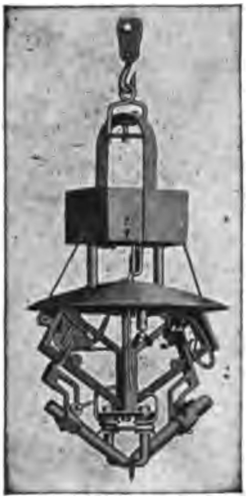


Fig. 57. Type of Zerener Welding Unit
Courtesy of Westinghouse Electric and Manufacturing Company

Zerener System. The Zerener system consists in having the two electrodes made of carbon and mounted in a frame which holds them at an angle with relation to each other and to the work, Fig. 57. The arc is drawn between them and is then deflected downward by a magnet and used in the same way as a gas flame. The apparatus for holding and feeding the carbon pencils is so bulky and complicated that this system has not been used in America to any great extent, although it is in use in several plants in Germany. The nature of the apparatus is such that large amounts of current cannot be used; so it is limited to comparatively light work. The weight and size of the holders for even moderate-sized work are such that they must be suspended from above by ropes and moved about over the work, although small holders for use in one hand have been developed for holding the lightest articles. The advantage claimed for this system is that the arc is controlled by a magnet and that finer work can be done.

ELECTRIC WELDING EQUIPMENT

Simple Equipment Wasteful. The equipment required for electric-arc welding depends largely upon the nature of the work to be done but, of course, the most complete apparatus does the best work, as in the case of any other sort of apparatus. The most elementary equipment consists of a barrel of water with two iron plates in it (using the resistance of the water to reduce the amount of current flowing) and an electrode holder, with some cables to connect the parts to the power circuit. This system can be used for cutting and for welding where roughness and uncertainty of results are no disadvantage. The current is varied by varying the space between the plates in the water barrel but this system is very wasteful and inefficient because the line voltage (usually 220 volts in shops and 550 volts for street railways) must be cut down to that required for welding (about 25 volts in the arc); this is done by dissipating the unused energy in the form of heat in the water. Sometimes resistances, made up of cast-iron grids, Fig. 60, are used instead of the water

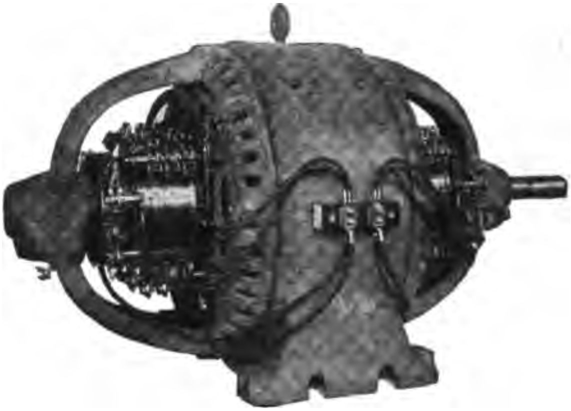


Fig. 58. 900-Ampere Welding Generator with Collector Rings at Each End for Taking Off Alternating Current
Courtesy of C & C Electric and Manufacturing Company

barrel, but they are more expensive and just as inefficient. This grid resistance is cut into and out of circuit by a series of switches.

Advantages in Low-Voltage Generators. The use of dynamo-electric machines of low voltage, Figs. 58 and 70, instead of resistances as just described, is preferable because of their higher efficiency and the better voltage regulation obtained. Fig. 59 shows a typical wiring diagram for the low-voltage equipment. It is well known among electrical men that a properly designed motor-generator set gives the best regulation of voltage and, when the generator is properly compounded, we have the ideal apparatus for electric-arc-welding. The leading systems in general use today consist of motor-generator sets with suitable control apparatus for motor, generator, and the welding and cutting circuits.

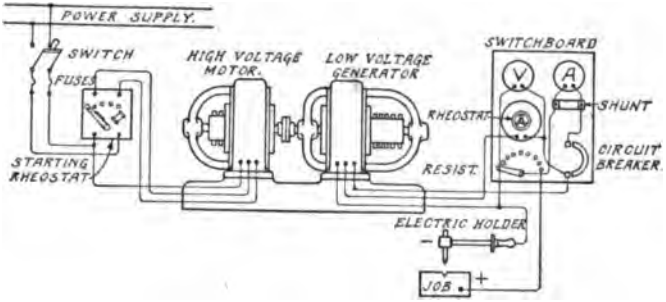


Fig. 59. Elementary Low-Voltage Arc-Welding Equipment

Single unit machines such as dynamotors, synchronous converters, etc., are also used, although the voltage regulation and current control are not quite so good as with motor-generator sets. For working with the graphite electrode and for the heavier classes of metallic electrode work they are all right, and a large number of them are in use in foundries, ship yards, railway shops, etc. A few of them are also being used in lighter work where the total load is not such as to cause a drop in voltage, and they make fine portable outfits because of their small size and light weight.

There are at present only seven companies of importance in the United States offering electric-arc-welding outfits, six of which use low-voltage generators and the seventh furnishing iron-grid resistances to reduce the voltage to that required for welding. The C & C Electric and Manufacturing Company has been in the field 11 years;

Westinghouse Electric and Manufacturing Company, 9 years; General Electric Company, 8 years; Lincoln Electric Company, 5 years; and the Burke Electric Company is just entering the field. These are the only companies manufacturing arc welders, although the Siemund-Wenzel Electric Welding Company is having apparatus made for it by the Crocker-Wheeler Company; the Welding

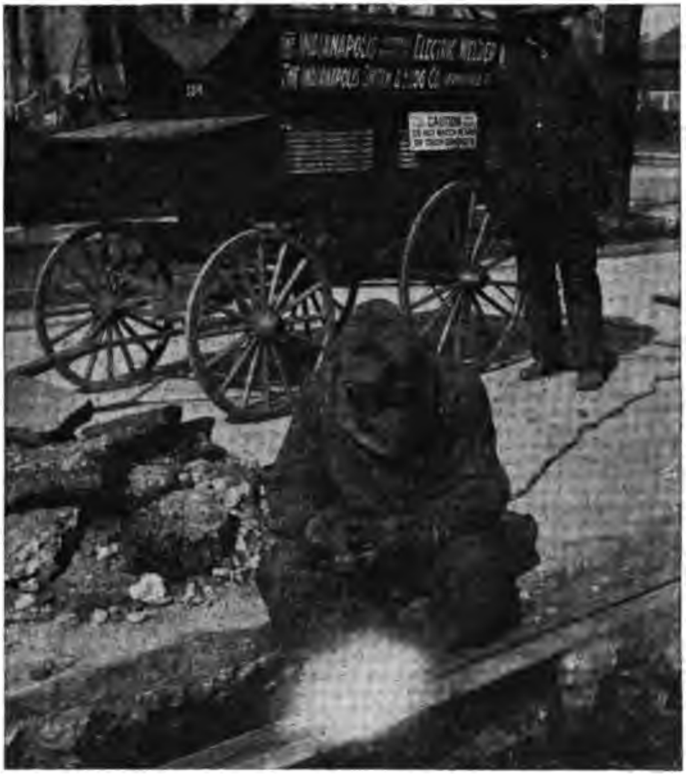

THE INDIANAPOLIS ELECTRIC WELDER
THE INDIANAPOLIS SWITCH & FROG CO.
CAUTION

Fig. 60. Portable Electric Welder in Action
Courtesy of Indianapolis Switch and Frog Company

Materials Company has its apparatus made by the Triumph Electric Company; and the Indianapolis Switch and Frog Company makes a resistance system, as stated. Each of these companies offers apparatus on the strength of some peculiarity of the controlling apparatus for the welding circuits or certain features of the welding machines.

Indianapolis Track Welder. The Indianapolis Track Welder, Fig. 60, consists of a group of iron resistance grids mounted in a framework on a four-wheeled truck, with means for making connection with the trolley wire to get current. It is used almost entirely for repairs on street railway tracks. The control device consists principally of a set of switches for varying the number of grids in series with the arc, an electrode holder and cables. The Slavianoff system is used for most operations, although the Benardos system may also be used. Owing to the low efficiency of operation they have not been adopted for use in industrial plants, but the cost is comparatively low and street railway companies do not seem to object to the enormous waste of energy incident to their use.

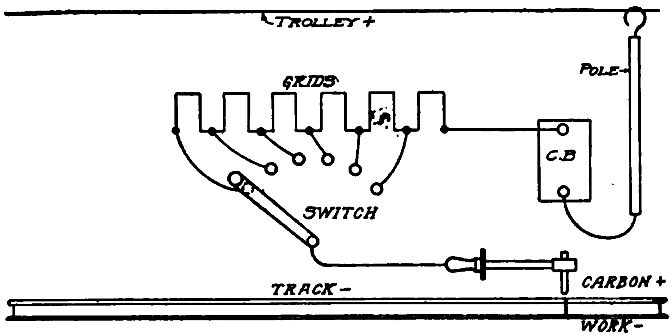


Fig. 61. Wiring Diagram Showing Principal Features of the Indianapolis Track-Welding System

The diagram of connections, Fig. 61, shows the relation of the various parts of this equipment and the switches for varying the current by cutting in or out the grids of the resistance. The nature of this system, as with water barrels, is such as to necessitate a separate outfit for each operator in order that he can adjust his current to suit the work in hand without interfering with the other operators.

Westinghouse Arc Welder. The equipment produced by the Westinghouse Electric Company consists of a motor-generator set with switchboards for controlling the machine and the welding circuits. The generator is a 75-volt compound-wound direct-current dynamo and is direct-coupled to a motor of proper capacity and suitable for operation from the power circuit available. Being a constant-potential generator, several operators may work from it at once if proper resistances and switches are provided for each circuit, and work may be done by either the Benardos or Slavianoff processes. An overload circuit breaker is provided for the protection of the generator from the effects of injurious overloads after welding has started.

With this apparatus various classes of welding and cutting may be done and the positive line is connected to the work and the negative to the electrode holder in the usual manner. The amount of current required for the work in hand is regulated by a series of switches which cut in or out sections of an iron grid resistance, and a small portion of the resistance bank is left in circuit continuously to steady the arc. This apparatus has been used almost entirely for graphite cutting and welding until recently when means were provided for using metallic electrodes also. Fig. 62 shows the principal elements properly connected for a single operator, and more circuits would involve the addition of the extra switches, resistances, and electrode holders for each of them. The apparatus for controlling the machine and the welding circuits is mounted on switchboard panels stationed near the motor-generator set.

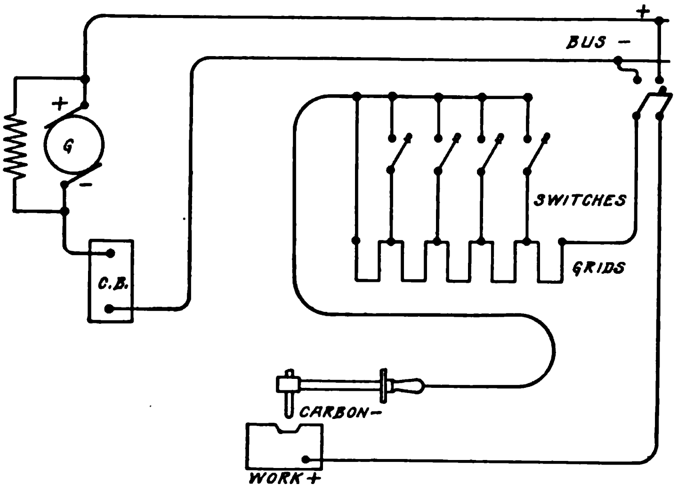


Fig. 62. Wiring Diagram for Westinghouse Arc Welder

Lincoln Arc Welder. The Lincoln Electric Company make both motor-generator sets and single-unit machines for welding equipments, both being similar in operation to the Westinghouse outfits just described. The wiring diagram shown in Fig. 63 shows the general connections. The single-unit machines are made as synchronous converters for use on alternating-current circuits or as dynamotors for use on direct-current circuits. The Lincoln dynamotor differs from others in that there is but one commutator, and the outgoing or generator circuit is taken from two extra brushes located between the motor brushes in the proper position to give current at the proper voltage. The amount of current is varied by varying the strength of the interpoles through switches and by the length of the arc. Resistances are used for varying the current from the alternating-current converters, and also from the motor-generator sets in the usual manner.

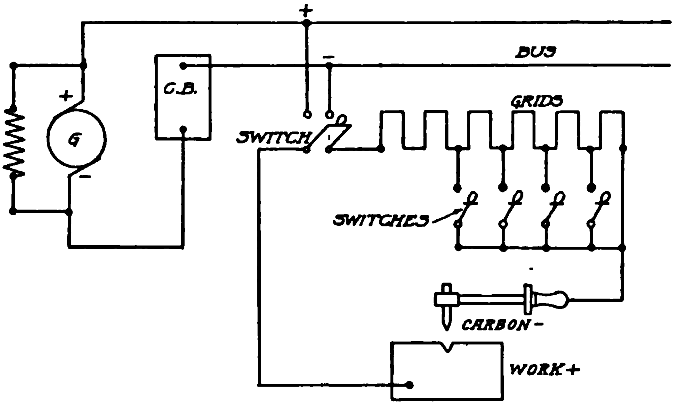


Fig. 63. Wiring Diagram for Lincoln Arc Welder

Switchboards are provided containing the apparatus for controlling the welding machine and welding circuits, and an overload circuit breaker is provided to protect the generator from dangerous overloads while working. The overload circuit breaker must be closed by hand if opened. The voltage regulation of the single-unit machines is not quite so good as with their motor-generator sets, of course, but work can be done by either the Benardos or Slavianoff process.

Siemund-Wenzel Welding System. This system is based upon the use of a single shunt-wound direct-current generator for each welding circuit, Fig. 64, and operates on the Slavianoff process.

The principal feature of this system lies in having the generator operating at full load all of the time, and using the current in the arc when welding or dissipating the energy through a resistance in the form of heat when not welding, Fig. 65. The circuit is thrown from the arc to the resistance by means of a solenoid switch, and only one man can work from each machine at one time.

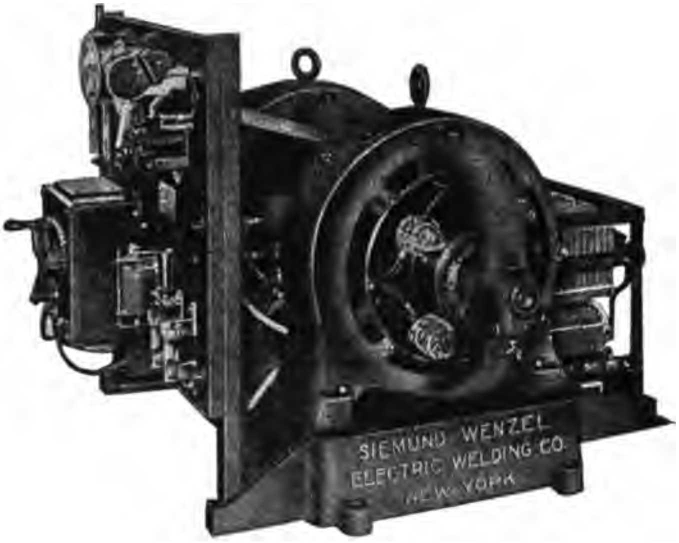


Fig. 64. Single Welder Siemund-Wensel Unit

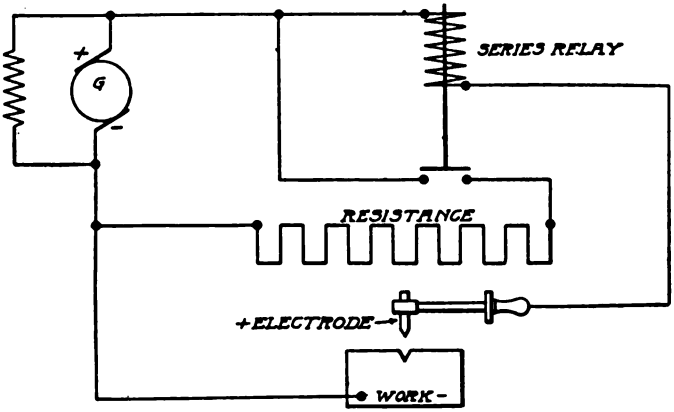


Fig. 65. Wiring Diagram for Siemund-Wensel System

The current is varied to suit different jobs by varying the voltage at the generator, but the current also varies with variations of arc length and tends to vary the amount of metal deposited. This company also uses an electrode holder with a coil embodied in the handle in such a way as to set up a magnetic field around the metallic electrode and arc, on the theory that it helps in depositing the molten metal in the weld, especially or overhead work. This is a doubtful advantage because molten iron and steel are non-magnetic, and in fact are practically so at temperatures as low as 700° centigrade.

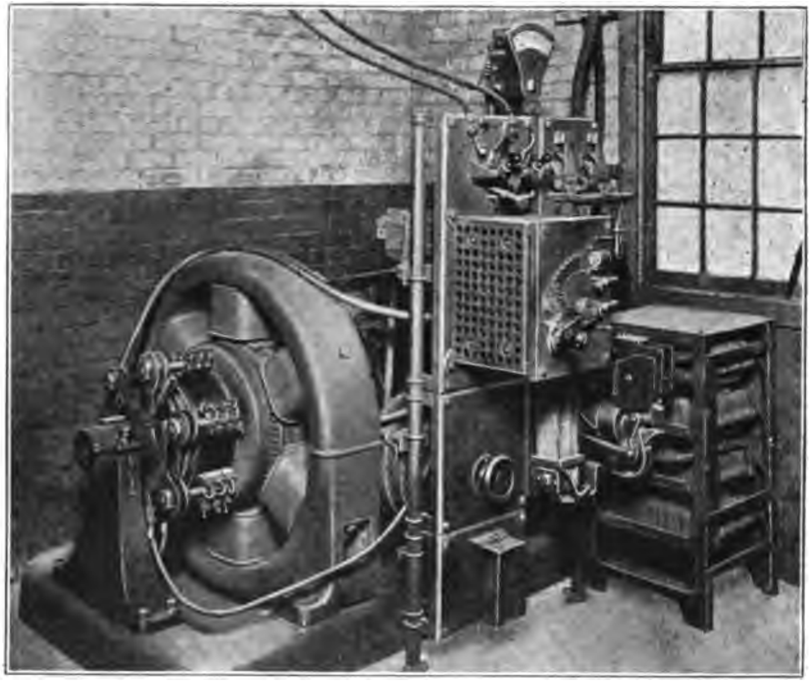


Fig. 66. Arc Welding Set with Automatic Overload Relay
Courtesy of General Electric Company

General Electric Arc Welder. The welding equipment developed by the General Electric Company, Fig. 66, consists of a compound-wound low-voltage direct-current generator, similar to those previously described, direct-coupled to a motor to suit the power supply, together with a switchboard containing the necessary devices for controlling the machine and the welding circuits. These equip-

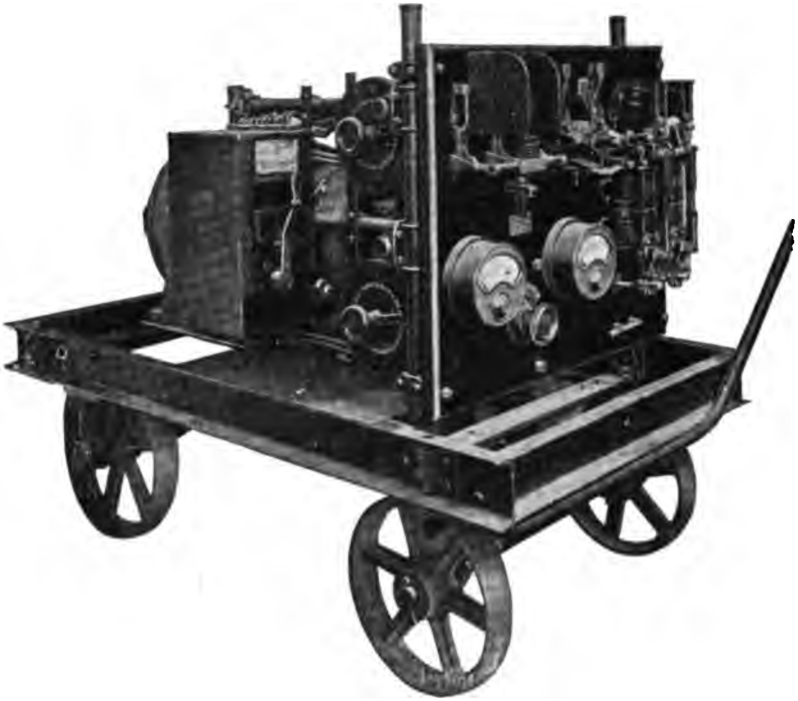


Fig. 67. Portable Welding Outfit
Courtesy of General Electric Company

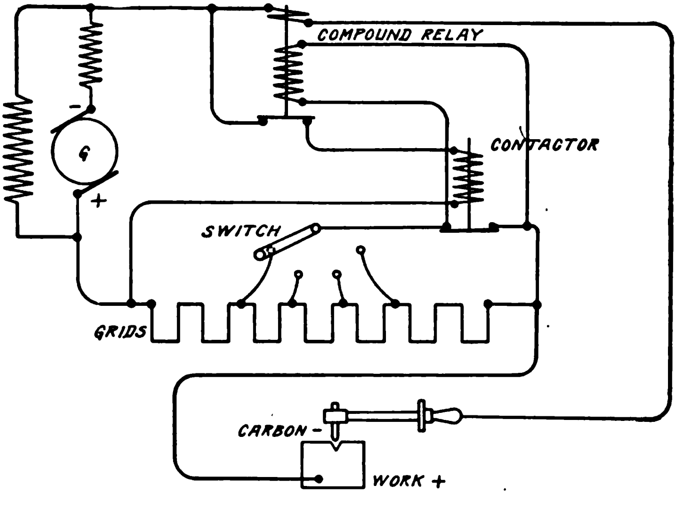


Fig. 68. Wiring Diagram for General Electric Welding System

ments are made in portable form also, Fig. 67, with the entire outfit mounted on a truck.

By reference to Fig. 68, it will be seen that the current flows from the positive side of the generator to the work through a bank of resistance grids; thence through the arc, electrode, relay, and back to the generator, negative side. The contactor opens and inserts resistance in case the relay is actuated by an overload, and the amount of current required in the arc for welding is varied by a multiple contact switch which cuts in or out sections of the grid resistance. Several men can work at once from machines of this type because of using the constant-voltage system, by adding enough circuit-controlling relays and contactors. The use of the overload relay described prevents injurious overloads on the generator, although the only limitation to current flow in the individual welding circuits of multiple-circuit equipments lies in the resistance in use at the time. In Fig. 69 is shown an operator using the graphite electrode on medium work.

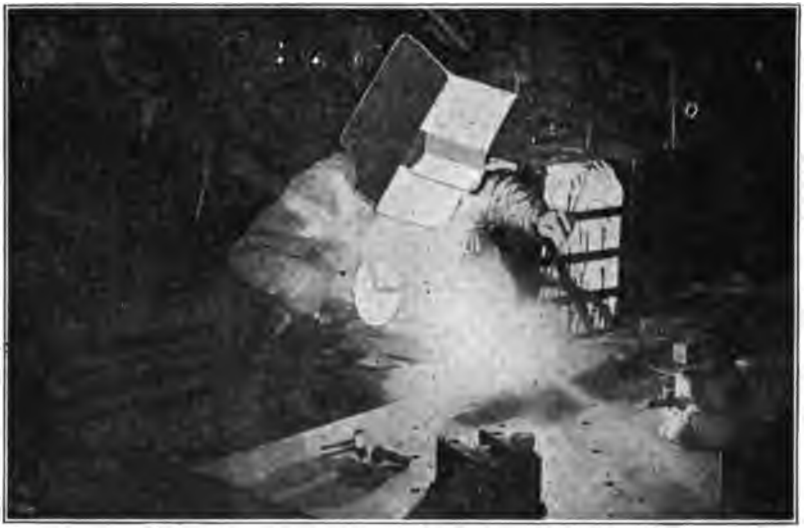


Fig. 69. Operator Using Graphite Electrode on Medium Work
Courtesy of General Electric Company

C & C Electric-Arc-Welding System. The C & C system of electric arc welding has been developed during a longer period than any of the others, because the C & C Company is the pioneer in that field in America and, consequently, has its control system developed to a higher degree and protected by numerous patents. The welding machine consists of either a single-unit machine or dynamotor for use on direct-current circuits, or a low-voltage compound-wound direct-current generator of high overload capacity direct-connected to a motor of proper size and suited to the power supply, both machines being mounted upon a substantial cast-iron base as indicated in Fig. 70. For controlling the motor and generator, a switchboard is supplied which may be mounted in any convenient position with relation to the machine and connected to the power circuit. On this panel are mounted the necessary instruments and switches for the welding machine and motor, and the apparatus for controlling the welding circuits is usually mounted upon separate smaller panels, although for portable equipments or single-circuit outfits everything is mounted on the main switchboard panel.

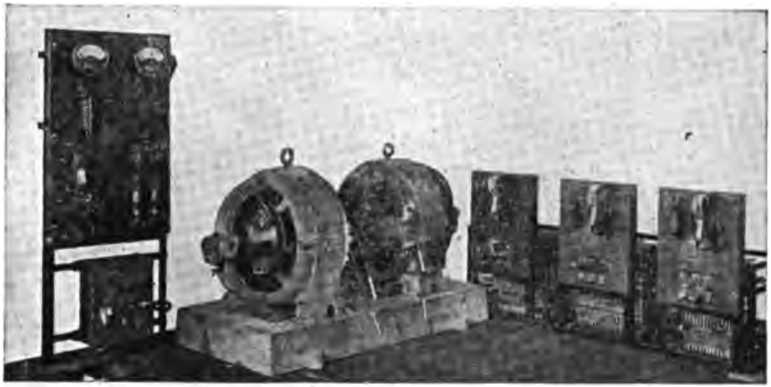


Fig. 70. 300-Ampere Welding Set with Control Panel and Auxiliary Welding Panels
Courtesy of C & C Electric and Manufacturing Company

Each welding-circuit control panel contains one of their patented automatic control outfits, and means are provided for preventing a rush of current when drawing the arc as well as for inserting a protective resistance to reduce the current in case of overload when using the graphite arc. By this means the thinnest metal, Fig. 71, or the heaviest castings, Fig. 72, may be welded safely and smoothly with equal facility, and the operation of the controlling devices is so entirely automatic that the operator does not have to go to the switchboard and close circuit breakers or other devices after once starting work. This system of welding has been developed for working by either the Benardos or Slavianoff process.

By referring to the diagram of connections, Fig. 73, it will be seen that the current flows from the positive side of the generator to the job, through the arc, electrode and holder, resistance, overload and series relays, and back to the negative side of the generator. The diagram shows the positions of the various items before the arc is drawn, and it will be noted that all of the resistance is in series with the electrode and other devices. The arc will, of course, be drawn between the electrode and the work in the usual manner, and it will be noted that the coil on the magnetic contactor is so connected as to be in shunt or parallel with the arc. When contact

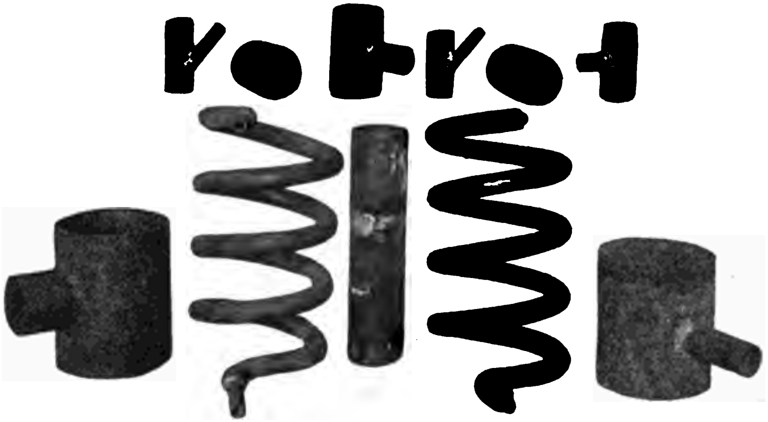


Fig. 71. Miscellaneous Pipe Welds with Light Tubing
Courtesy of C & C Electric and Manufacturing Company

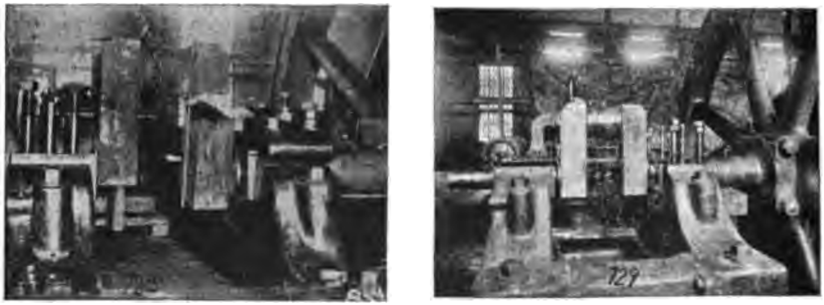


Fig. 72. Broken Steel-Forged Crankshaft Welded with Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

is made between the electrode and work to establish the flow of current and strike the arc, the coil of the series relay will be energized and it will close and energize the coil of the magnetic contactor. The contactor will not close, however, until after the electrode has been removed from contact with the work and the arc formed, because that contact is of lower resistance than the coil in shunt with it. So long as the magnetic contactor is open, all of the grid resistance is in circuit and the flow of current is too small to burn the work or overload the generator. As soon as the arc is drawn, that path becomes of higher resistance than the path through the shunt coil on the contactor, hence the magnetic contactor coil gets current enough to close the contactor and cut out resistance until enough current flows to suit the job in hand as predetermined by the setting of the resistance switch. In case of overload while working, the overload relay open-circuits the coil of the magnetic contactor and causes it to open and re-insert the entire resistance, cutting the current to the minimum without rupturing the arc.

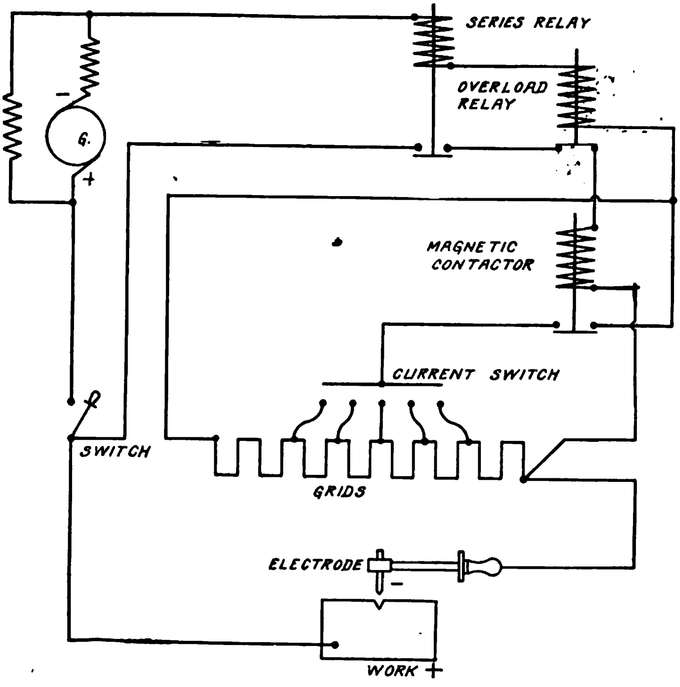


Fig. 73. Wiring Diagram for C & C Welding System

Owing to the use of a separate panel for each welding circuit, it is possible to have as many operators working at once as conditions require, tapping the panels off the distribution circuit from the machine panel the same as would be done with so many motors from any other circuit. The only limitation is that the generator shall be of sufficient capacity to furnish the current required. Another feature of this system lies in the use of an automatically self-closing overload circuit breaker on the main control panel for the motor, thus restoring the motor circuit automatically after the overload on the welding circuit or generator is removed. These outfits are also made portable, as shown in Fig. 74.

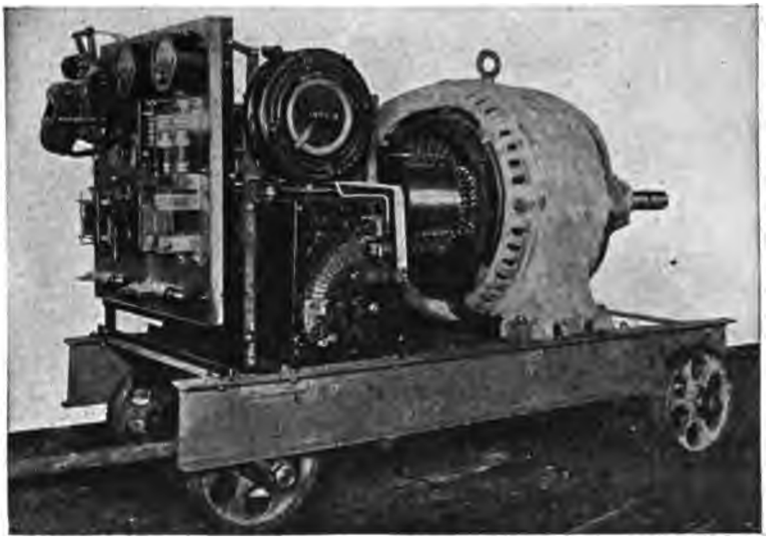


Fig. 74. 600-Ampere Portable Single-Unit Welding Outfit
Courtesy of C & C Electric and Manufacturing Company

In addition to the constant-voltage apparatus just described, the C & C Company also makes a variable-voltage welding outfit for use when but one operator is to work from the machine. This consists of a differentially-wound compound-generator driven by a suitable motor, with proper controlling devices mounted upon a switchboard panel. With this outfit work is done with as low as 12 volts drop in the arc and at a very high efficiency. The generator voltage varies automatically to keep the current constant at the predetermined value, regardless of the arc-length.

Welding Materials Company System. This company has recently brought out a machine to replace that formerly handled by them, based upon the use of a compound-wound generator of the variable-voltage constant-current type having an auxiliary exciter. This exciter is provided with a special differential winding, which changes the voltage supplied to the main generator field. Therefore, the action of the welding current in the end automatically regulates the voltage of the main generator so as to keep the current constant and at the predetermined value regardless of variations in the resistance of the welding circuit. The proper current for the work in hand is obtained by regulating the field of the machine before starting work, after which it is kept constant by the machine. Owing to the use of low voltage (usually between 10 and 20 volts with a maximum of 30 volts) the efficiency is considerably better than machines operating at higher voltages, and machines of this type are coming into greater use where but one man is to work from a machine. It is impossible to work two or more men at once from apparatus of this type, multiple-circuit outfits always being of the constant-voltage type with resistance in each circuit to vary the current. Variable-voltage generators are driven by suitable motors and have the controlling devices on switchboards in the usual manner. Of course, with this system, no resistances are required.

Burke Electric Welder. The equipment offered by this company has lately been placed on the market and consists of the usual low-voltage machine with welding circuits containing regulating resistances, similar to those described for the Westinghouse and Lincoln outfits.

Quasi-Arc-Welding Method. An English system known as the "quasi-arc-method of welding" has been used to a limited extent abroad, but has not been received very kindly in America because of the expensive electrodes used. This is based upon the use of wires or electrodes coated with a flux for preventing oxidizing.

Kjellburg System. The Kjellburg system is also based upon the use of a flux on the wire and the users of it make some very strong claims for it, but experience shows that work can be done satisfactorily without flux for every kind of welding. With both of the above types of electrodes, any of the apparatus described may be used.

WELDING OPERATIONS

Amount of Current Used. Welding operations are of various kinds and take different amounts of current, depending upon the nature of the material worked upon, the size and shape of the piece, and the sort of operation to be performed. For example, thin steel sheets require less current than thick ones; cutting requires a larger amount of current than welding, etc. As a general rule it may be said that metallic welding operations usually require from 50 to 150 amperes, although thin sheets may be welded with as little as 15 amperes and extra heavy ones may take 185 or 190 amperes; graphite arc welding, on the other hand, averages from 350 to 500 amperes, running from 100 amperes on small articles up to 600 amperes on heavy work. Cutting with the electric arc requires from 300 amperes on small sections up to 1000 amperes or more, the average job taking from 400 to 600 amperes. The nature of the equipment supplying the energy will affect the amount of current required to some extent, those with the best control systems being the most economical.

Plate Welding. The rate at which welding can be done depends upon the article to be welded, its size and shape, material, nature of weld, etc., Table II indicates the speed of welding seams in sheet steel.

TABLE II

Data on Steel Plate Welding

THICKNESS	DIAM. ELECTRODE	AMPERES	SEAM WELDED
28 to 20 gage	18 B. W. G.	10 to 25	30 ft. per hour
18 gage to 1/8"	1/16" diam.	20 to 40	25 ft. per hour
1/8" to 3/16"	3/32" diam.	30 to 60	20 ft. per hour
3/16" to 1/4"	1/8" diam.	50 to 100	15 ft. per hour
1/4" to 3/8"	5/32" diam.	75 to 150	10 ft. per hour
Over 3/8"	5/32" diam.	150 to 180	Variable

The figures given in the last column are only approximate, as they may easily be exceeded by an expert operator, but they give a fair average. These apply to seams made by butting the edges of the plates together and welding along in the space between them. The edges of the plates should be beveled sufficiently to allow the filling material to penetrate the full thickness of the plates, Fig. 75, or else a satisfactory weld will not result. Thicker plates than those given may also be welded and the time will vary as the square of the thickness. This is based upon one-fourth of an inch as the standard because that is about the thickest plate which may be satisfactorily welded by going along the seam but once. For thicker plates it is necessary to go along the seam several times in order to fill the slot properly and the area of the slot increases approximately as the square of the thickness when a V-shaped groove is to be filled. When an X-shaped slot, or two V slots, can be formed by beveling the plates on both sides, then the time required to make the weld is cut in two, and the rate of welding varies about in the same ratio as the thickness of the plates. The metallic electrode is used almost exclusively for steel plate and sheet welding, although the graphite electrode is sometimes used for heavy plates, when it is possible to work with the plates laid in a horizontal position, thus preventing the molten steel from running off.

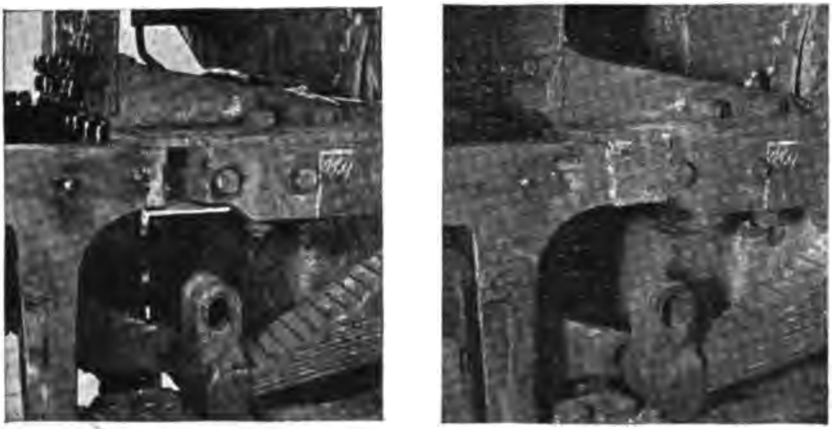


Fig. 75. Fractured Locomotive Side Frame Cut Out with Graphite Electrode and Welded with Metallic Electrode
Courtesy of C & C Electric and Manufacturing Company

Castings. When castings of iron or steel are to be welded, it is necessary to prepare a large enough space to work in; otherwise it will be impossible to join the pieces throughout their thickness. This is due to the fact that the filling material is not so liquid as that used with brazing and consequently will not flow in a small crack, but must be allowed to run easily into the space. With steel castings, and for some classes of small holes in large iron castings, the metallic electrode may be used but, for most cast-iron pieces and very large steel pieces, it is necessary to use the graphite arc and a melt bar for the best results. For cast-iron welding it is desirable to preheat all but the smallest and simplest pieces before welding in order that the high-shrinkage factor of the metal will not cause cracks when the weld is cooling. It is also good to reheat after welding and allow the piece to cool slowly in order to insure a weld soft enough to machine. A good welding flux is also an advantage when making cast-iron welds in order to help raise the slag and improve the quality of the weld. Iron with about 25 per cent of silicon should be used for cast-iron welding, and steel with from 25 per cent to 40 per cent excess of carbon, manganese, vanadium, or other desired content should be used when welding steel castings containing the elements mentioned.

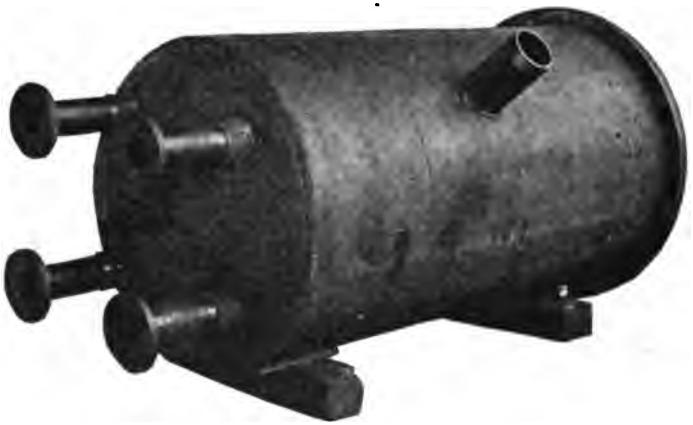


Fig. 76. Tank with Head, Flange, and Branches Welded in Place
Courtesy of C & C Electric and Manufacturing Company,

Copper and Aluminum. Copper and aluminum sheets, bars, and castings may be welded with the electric arc by using the graphite electrode and puddling in the filling. This operation is similar to welding cast iron and can be done only with the work laid in a horizontal position to prevent running. Owing to the necessity for using the graphite electrode instead of a piece of wire, it is evident that thin sheets cannot be successfully welded by this process. But sheets over one eighth of an inch thick have been welded, both of aluminum and copper, and castings as thin as one-fourth of an inch also. It is necessary to build a simple mold of clay around the spot to be welded in order to hold the molten metal, but it is a very simple process and requires but the smallest amount of current which will melt the metal. Large amounts of current tend to burn the material and, if zinc is present (as in brass), it will volatilize or burn out and leave a porous and useless weld. The same thing applies to bronze alloys containing manganese, phosphorous, etc., but in a lesser degree. In other words, when welding alloys of any kind, it is necessary to use that current which is suited to the most volatile element in the mixture. The others will get heat enough to flow sufficiently for all practical purposes in most cases and experience will soon show any operator the best methods of handling any of the alloys.

Boilers and Tanks. Boilers and tanks offer one of the best fields for the application of the Slavianoff, or metallic welding, process and the adoption of this method in manufacturing, Fig. 76, as well as in repairing such articles instead of riveting them, Fig. 77, is proceeding very rapidly. Joints, which have been properly welded with a metallic electrode of suitable size and composition and with the right amount of current, will be stronger than riveted seams. If the joint is reinforced slightly by additional filling material, it will be stronger than the original plate but, even when ground flush with the thickness of the plates, it will show from 85 per cent to 90 per cent of the strength of the plates for thick stock, and up to over 95 per cent of the strength for thin stock. The various methods in use for welding the seams in tanks are shown in Fig. 78, those welded in two places being best for high pressure. These may be compared with the usual boiler riveted joints in Fig. 79. Since the strain on the longitudinal seams is double that on the circumferential seams, it is customary to lap-weld the side seams for strength. When the tank or boiler is intended for use under high pressures, it is better to lap all seams; then a butt strap is added to the side seams and welded at both sides and the center,

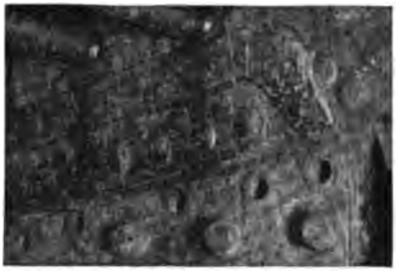


Fig. 77. Patch in Boiler with Seam Prepared for Welding

as indicated in one detail. The method of welding the head depends upon the shape of it, the convex head being the most common and flanged to slip inside the shell, and the welded seams are clearly indicated in the figure.

Boiler makers have been slower to take up electric welding than have the tank makers because greater restrictions having been imposed upon them in the interests of safety and reliability, they are generally more conservative. But there is a strong tendency now to use electric-arc welding to an increasing degree and boards

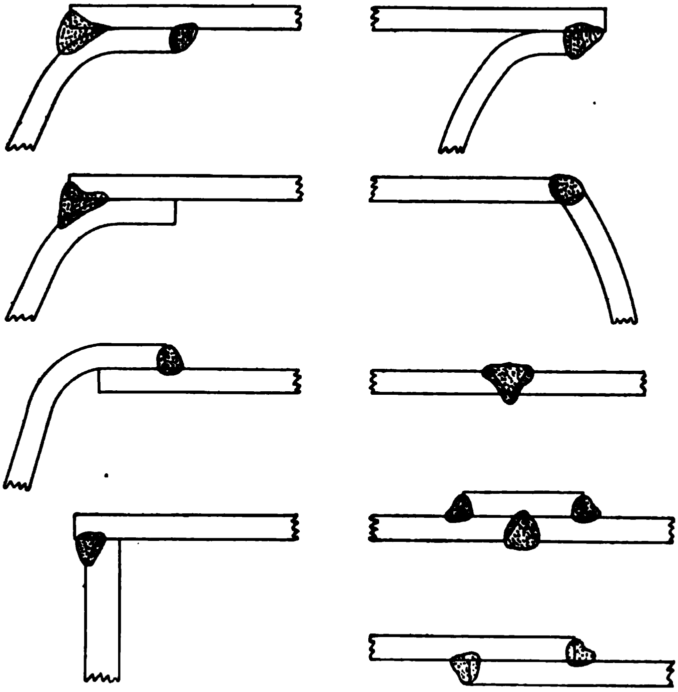


Fig. 78. Methods of Making Welded Seams in Tanks
Courtesy of C & C Electric and Manufacturing Company.

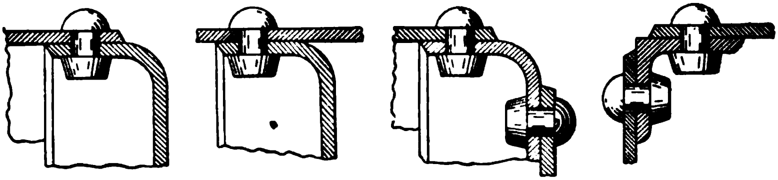


Fig. 79. Methods of Making Riveted Seams in Tanks

of inspectors and other official bodies are more liberal each year. By welding along the edges of the plates instead of calking with a hammer, Figs. 80 and 81, the plates are tied together and strengthened as well as tightened and the job never has to be gone over again. If the plates are badly corroded, they may be restored to their original thickness or to a greater thickness and leaking rivets may be tightened by welding around the heads and fusing them to the plates.

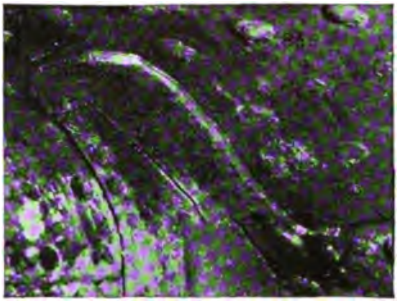


Fig. 80. Weld in Locomotive Fire Box
Courtesy of C & C Electric and Manufacturing Company

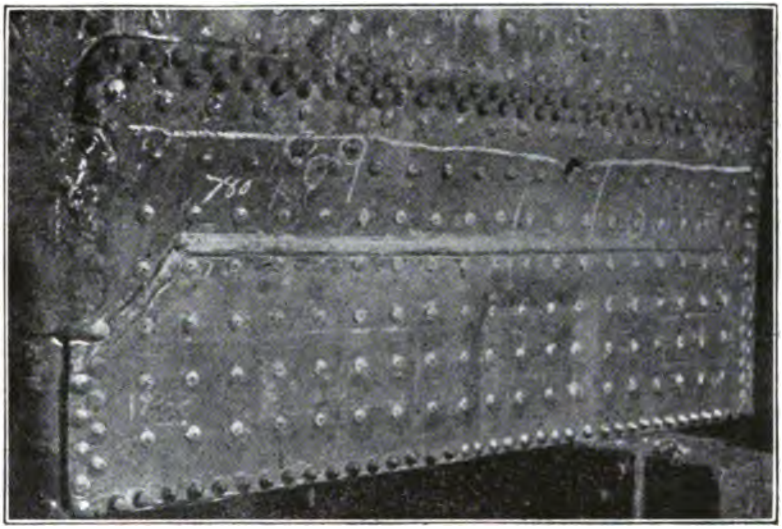


Fig. 81. Boiler Side Sheet Welded by Electric Welding Apparatus
Courtesy of The Boilermaker

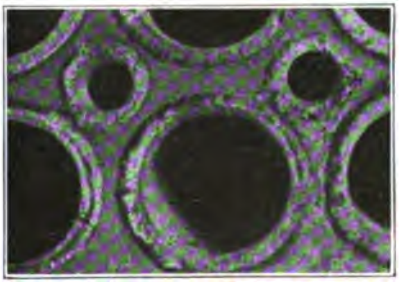


Fig. 82. Electrically-Welded Boiler Flues
Courtesy of Railway Master Mechanic

Welding Boiler Flues. One of the most important applications of metallic welding is in the welding of flues of locomotive boilers, Fig. 82. The flue end is expanded, beaded, and prossered in the usual manner, without the copper ferrule in the sheet, and then the edge of the bead is welded all around so as to attach it firmly to the sheet. This makes tubes and sheet one piece and eliminates leaking entirely, the life of the

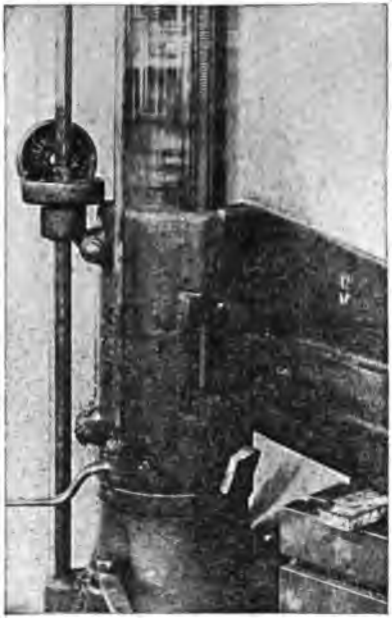


Fig. 83. Broken Housing of Radial Drill
Courtesy of C & C Electric and Manufacturing Company

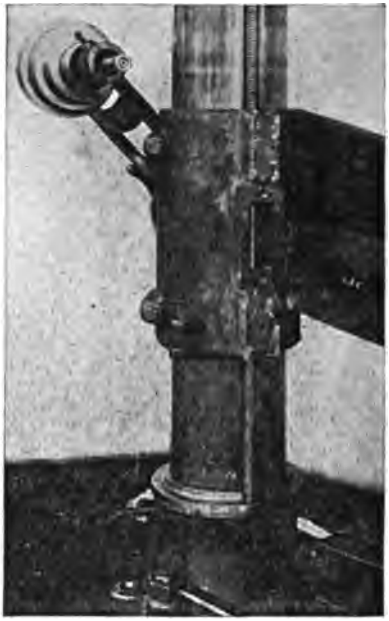


Fig. 84. Radial Drill Housing Welded with Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

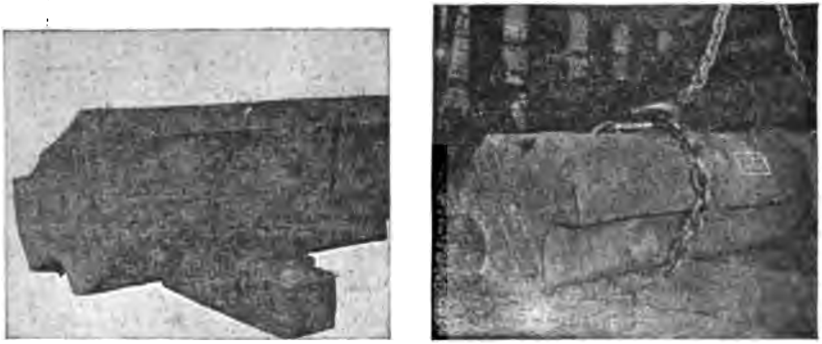


Fig. 85. Broken Steel Wabbler for Rolling Mill Welded with Graphite Electrode
Courtesy of C & C Electric and Manufacturing Company

TABLE III

Chemical Analysis of Iron and Steel Before and After Welding

Element	Sample No. 1, Iron		Sample No. 2, Steel	
	Per Cent Before	Per Cent After	Per Cent Before	Per Cent After
Silicon	0.009	0.003	.004	0.00
Carbon	0.015	Trace	.048	0.25
Sulphur	0.025	0.020	0.04	0.04
Phosphorus	0.068	0.043	0.08	0.07
Manganese	0.64	0.27	0.50	0.25
Iron (by difference)	99.108	99.664	98.86	99.39
Total percentage	100.000	100.000	100.00	100.00

weld being that of the tube itself. The law demands new flues every three years; so they cannot be used longer, but it is known from the life of welds in fire boxes that the weld will last as long as the sheet; there are about two thousand locomotives running in the United States today with some part of the boiler welded, most of them with the flues welded in. Broken mud rings may easily be welded in place by cutting out a piece of the sheet at the break, welding the ring, and then welding the piece of plate back again.

Welding Machine Parts, The use of the electric arc for welding machine parts, new and broken, Figs. 83 and 84, is another field that offers great savings because of the delay incident to getting new parts as well as their cost, in cases of breakage, Fig. 85, and the great expense of making satisfactory mechanical joints in new work. Radical changes in design and details of construction are made possible by the use of this system in machine building and the fact that the parts can be so joined as to be literally one piece opens up great possibilities. For work on cast iron the graphite electrode is used and a cast-iron melt bar fused into place with the article in a horizontal position. Cast-steel parts requiring a moderate amount of welding may be done with the metallic electrode but large welds can usually be done to better advantage with the graphite electrode, using a wrought-steel melt bar or pieces of steel plate scrap to fill in with. Cast iron or steel can be welded soft enough to machine readily, by proper treatment, and the quality of the welded section can be made equal to the rest of the article. The effect of the electric arc on the composition of the metal is clearly indicated by Table III.

TABLE IV

Strength of Butt-Welded Joints

Plate Thickness Inches	Elastic Limit Lbs. Per Sq. In.	Tensile Strength Lbs. Per Sq. In.	Elongation % in 8 In.	Per Cent Efficiency
$\frac{1}{4}$	40930	54650	4.5	97.6
$\frac{3}{8}$	44930	53020	5.75	94.7
$\frac{1}{2}$	40160	51280	4.75	91.6

From Table III, it will be seen that it is necessary to use filling material of the proper composition if the weld is to be the same in composition as the original article. By merely using electrodes and melt bars with an excess of such elements as silicon, carbon, etc., this can be controlled to a very small variation from the desired amount. Unless the operator burns his metal by using too much current or applying it too long, there will be no appreciable

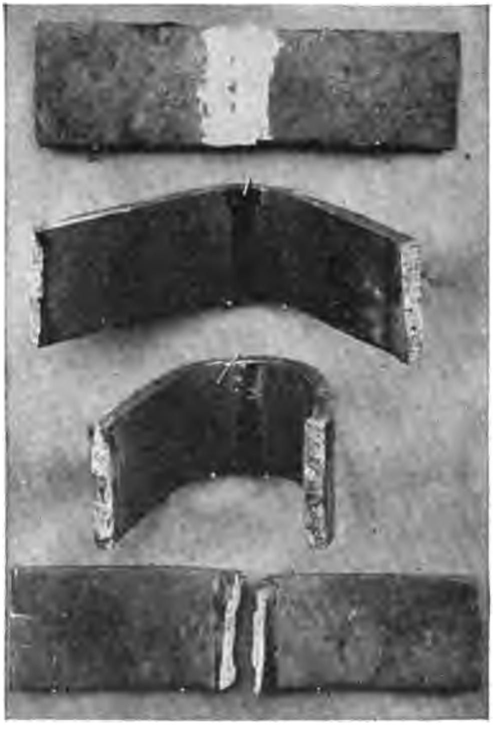


Fig. 86. Test Plates Showing Strength of Electric Welds
Courtesy of C & C Electric and Manufacturing Company

TABLE V

Relative Strength of Joints

Samples and Preparation	Breaking Strain Pounds	Length After Breaking Inches	Per Cent Efficiency
Original piece of plate................	58,600	8.80	97.66
Lap joint, arc welded..................	54,800	8.94	91.33
Lap joint, riveted and welded........	54,200	9.22	90.33
Butt joint, arc welded...............	47,800	8.28	79.66
Butt joint, acetylene welded.........	36,800	8.23	61.33
Lap Joint, riveted only..............	35,000	....	58.33

difference in color between the weld and the rest of the piece; so finished surfaces may be welded in many cases.

Strength of Weld. *Butt-Welded Joints.* The strength of the weld can be made the equal of the article welded by reinforcing, or it can be made very nearly equal by using filling material of high strength and welding flush with the surface of the piece, Fig. 86, this being especially true of steel plates. Some tests made for the author on steel plates of various thicknesses (with a nominal strength of 56,000 lbs. per square inch) showed the results given in Table IV.

The elongation in the filling material was less than in the original material, of course, owing to its being really a steel casting, but its ductility can be improved by hammering after welding and this is frequently done when welding heavy sections.

Comparative Test. In order to test the relative strengths of riveted, electric-arc-welded, and acetylene-welded joints, a set of steel samples were made up and tested as follows, each piece being $\frac{3}{8}$ inches by $2\frac{13}{32}$ inches in cross section and 8 inches long in the straight portion, Table V.

The steel plate used had a nominal strength of 60,000 pounds per square inch but was actually not up to standard, although it showed clearly the relative advantages of the various methods of making joints. Some tests recently made in England are shown in Table VI. Strength of welded piece was 88.43 per cent of original plate.

TABLE VI

Relative Strength of Original and Welded Plate

	Size of Sample Inches	Breaking Strain Pounds	Per Cent Elongation in 4 Inches	Per Cent Reduction of Area
Welded piece...........	.125×1.48	42,702	10.93	5.23
Original piece...........	.125×1.48	48,290	32.03	29.63

TABLE VII

Time and Cost of Welding

Article Welded	Time	Cost
Steel casting, shrinkage crack 6″ long by 1″ deep	8 min.	$00.04
Steel casting, riser 4″ by 4″ cut off	4 min.	.05
Forged steel locomotive frame, broken in 2 places	20 hrs.	18.28
12″ crack in back sheet of locomotive boiler	9 hrs.	5.47
Building up worn driving wheel instead of turning down	2 hrs.	.72
Welding 67 cracks in old fire box (saving over $1000)	2 wks.	52.60
Cast-steel tender frame, broken in 3 places	27 hrs.	19.00
Steel shaft, 2″ diameter, broken, welded ready to finish	1 hr.	.60
Broken railway type motor case, cast steel, welded	3 hrs.	1.95
Enlarged holes in brake levers, steel bars	4 min.	.05
Building up 2″ armature shafts, worn in journals	3 hrs.	1.80
Air brake piston rods, broken, welded ready to finish	30 min.	.35
Leaking axle boxes, cracks, welded in position	15 min.	.15

Cost of Arc Welding. The cost of arc welding will vary according to the nature of the work, the skill of the operator, and the cost of labor and current, but it is much less than for similar work done by any other process. It ranges from about three-fourths down to one-tenth that of the cost of acetylene welding, for various jobs, and the time required is much less. With the electric arc it is not necessary to keep a large portion of the work heated in order to prevent the chilling of the filling material, because the work forms the hottest (positive) terminal of the arc and a sufficient volume of heat is generated at the point which is being worked upon to insure perfect fusion.

Cost Data in Steam Railroad Shops. The figures in Table VII show the cost of several actual jobs done with arc welders, the labor being paid at the rate of 30 cents per hour and the current costing 2 cents per kilowatt hour, with the filling material figured at 8 cents per pound.

Comparison with Old Methods. The figures in Table VII will give a fair idea of the class of work and the costs of welding in steam railroad shops and car shops, and those in Table VIII will show the savings effected through the use of arc welding instead of making repairs by the old methods, of whatever kind.

Street Railway Repairs. Repairs to electric railway apparatus are also important in order to keep the rolling stock in useful service. The figures in Table IX, which give average costs for performing typical repair jobs in street car shops, are based upon the

TABLE VIII

Relative Costs of Repairs

Article Welded	Welding	Old Cost	Saving
Engine main frames, both broken	$11.80	$56.20	$44.40
Driving wheel built up $\frac{3}{16}$" on tread	.72	8.00	7.28
General repairs on fire box side sheets	66.51	342.62	276.11
Filling worn knuckle joint bushing hole	.75	7.50	6.75
Welding 7 cracks in locomotive cylinder	22.35	367.15	344.50
Broken mud ring on locomotive boiler	32.07	118.06	85.99

relation between the cost of electric welding as opposed to replacement because that is usually the alternative.

One of the electric railway companies claimed that they repaired about 1600 articles a year which, if replaced by new pieces, would cost them nearly $15,000.00, and had also the benefit of the large amount of time saved by doing the work quickly and keeping their rolling stock in service a larger portion of the time. The use of electric-arc welding apparatus is not confined to the railway field, but equally interesting figures could be given as applying to work done in foundries, machine shops, boiler and tank shops, garages, and other places. These few will serve, however, to show the possible savings through using the arc for repair work in general.

In conclusion, it should be remembered that in order to weld with the arc it will require some practice in starting the arc, especially with the metallic electrode. The "trick" consists in touching the work and getting away as quickly as possible to the required distance, and yet not going so far as to rupture the arc. If the electrode is of metal, it will heat and stick to the work unless withdrawn quickly,

TABLE IX

Street Railway Repairs

Article Welded	Welding	New Part	Saving
Armature shaft, repaired in place	$ 1.70	$ 4.72	$ 3.02
Armature shaft, large, repaired in place	1.97	15.13	13.16
Railway motor axle cap, large	.22	3.51	3.29
Railway motor armature bearing cap	.27	6.07	5.80
Railway motor gear case, top half	.48	7.30	6.82
Truck side frame, Brill 27-G	.72	44.40	43.68
Truck side frame, Peckham 14-B	.90	46.98	46.08
Brake head, building up worn socket	.06	1.15	1.09
Motor frame, G. E. 90, railway type motor	2.88	16.80	13.92

but it can easily be broken loose by a twisting motion of the hand. Care should also be exercised to see that the eyes and face are fully protected from the glare and heat of the arc, as it is hard on the eyes and affects the skin like bad sunburn. On the other hand, some men have done arc welding for years with no injury.

ELECTRIC-ARC CUTTING

Advantages of the Method. Cutting with the electric arc can be done very rapidly and economically and is done a great deal in foundries, scrap yards, Fig. 87, and other places. The slot cut is not so narrow as that cut by a gas flame, which is discussed later, but the metal is good after fusing out and may be used again. This is not always the case with metals cut by gas processes because there is a chemical action between the gases and the metals, whereas the arc is composed of the vapors of the metals worked upon and, aside from a slight oxidation when cutting iron or steel, there is no injurious change in the metals cut. Some of the more volatile elements may be reduced by the high temperature but the mass being cut will remain unchanged.

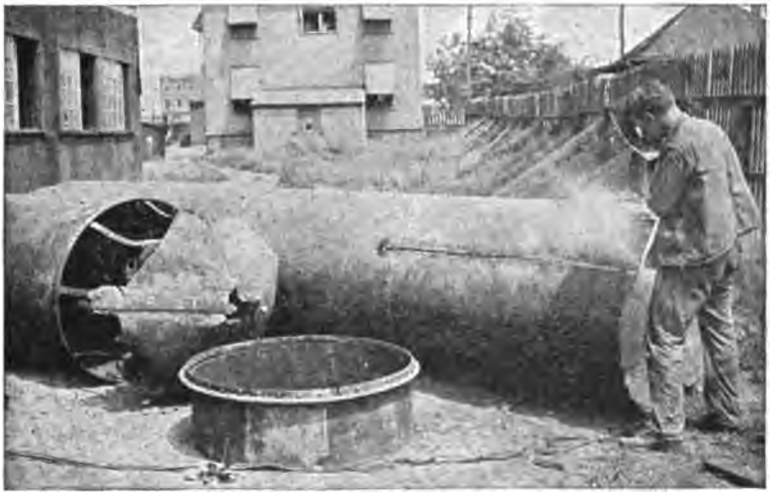


Fig. 87. Cutting Scrap with a Carbon Electrode
Courtesy of C & C Electric and Manufacturing Company

Current Requirements. Cutting is done with the graphite electrode and requires from 100 amperes on sheet metal up to several hundred on heavy castings and forgings. The maximum current which it is practical or necessary to use should never exceed 1000 amperes and the usual cutting operations take from 400 to 600 amperes. Direct current at 70 volts is used, the same as for welding, and almost any source of supply will give satisfactory results if proper means are provided for controlling the current. However, apparatus which has been specially developed for the service is much better and more reliable than makeshift devices and, as experience shows that the cost of cutting is just as important as the cost of welding, dead resistances should not be used.

Rate of Cutting. The rate of cutting has been found to be very close to one square inch of cross section per minute for each 100 amperes used in the arc. This rate will be increased slightly for sheet-metal work but applies very closely for heavy sections. On the basis given, a section 4 inch by 6 inch (24 square inches) can be cut in 4 minutes with 600 amperes, and experience shows this to be true. A steel plate 1 inch thick and 1 foot wide (12 square inches) can be cut in 2 minutes with 400 to 450 amperes; copper, aluminum, and other metals can be cut at about the same rates as steel sheet. When cutting it is necessary to make the slot wide enough to allow the arc to reach to the bottom of the cut instead of jumping to the sides and the piece should be placed so that the molten metal can run out of the slot. Work should begin at the top of the piece.

ELECTRIC BUTT AND SPOT WELDING

Characteristics and Development of the Process. The use of the electric current to heat metals to the welding point, by passing the current through the joint until the metal becomes plastic and then applying sufficient pressure to cause the pieces to adhere, was first proposed by Elihu Thomson in 1877; and the present day process of "resistance welding", in its various forms, is the result of his work. The process is based upon the phenomenon that a poor conductor of electric current will heat if current is forced through it, or that a good conductor will also heat if enough current is passed through it, and that the heating effect will be greater if alternating current is used than if direct current is used. Since an imperfect joint between two pieces of metal is a poor conductor and offers resistance to the passage of current, it will naturally heat and finally cause the metal to soften sufficiently to weld. In practice the operation is very rapid because comparatively large amounts of current are used and heavy pressures are applied.

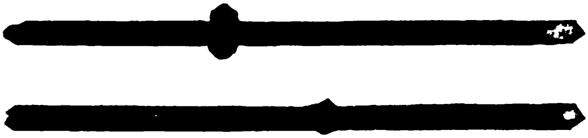


Fig. 88. Welded Bars Showing Upset
Courtesy of Toledo Electric Welder Company

Originally this process was used to weld bars and strips together, end to end, Fig. 88, performing the operation known as "butt welding", and this is today one of the principal uses of the system. Later a modification of the system was made in order that pieces of sheet steel could be welded; this resulted in the development of the operation known as "spot welding", by means of which lapped joints can

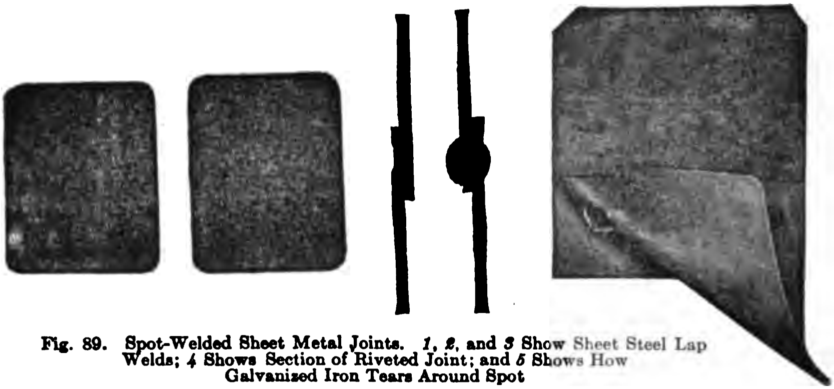


Fig. 89. Spot-Welded Sheet Metal Joints. *1*, *2*, and *3* Show Sheet Steel Lap Welds; *4* Shows Section of Riveted Joint; and *5* Shows How Galvanized Iron Tears Around Spot

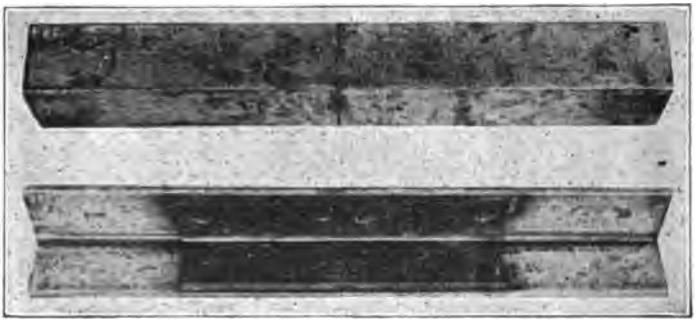


Fig. 90. Single Strap Butt Joint, Spot Welded
Courtesy of Toledo Electric Welder Company

TABLE X

Metals, Alloys, and Combinations of Different Metals Actually Welded by the Thomson Process

METALS					
Wrought Iron	Wrought Copper	Tin	Cobalt	Aluminum	Gold (pure)
Cast Iron	Lead	Zinc	Nickel	Silver	Manganese
		Antimony	Bismuth	Platinum	

ALLOYS					
Various Tool Steel	Mushet Steel	Wrought Brass	Fuse Metal	Aluminum and Iron	Silicon Bronze
Various Mild Steel	Stub Steel	Gun Metal	Type Metal	Aluminum Brass	Coin Silver
Cast Steel	Crescent Steel	Brass Composition	Solder	Aluminum Bronze	Gold Alloy
Chrome Steel	Bessemer Steel	Nickel Steel	German Silver	Phosphor Bronze	

COMBINATIONS					
Copper to Brass	Brass to Wrought Iron	Brass to Tin	Wrought Iron to Tool Steel	Wrought Iron to Mushet St.	Wrought Iron to Nickel
Copper to German Silver	Tin to Zinc	Brass to Mild Steel	Gold to German Silver	Wrought Iron to Stub Steel	Tin to Lead
Copper to Gold	Tin to Brass	Wrought Iron to Cast Steel	Gold to Silver	Wrought Iron to Crescent St.	Mild Steel to Tool Steel
Copper to Silver	Brass to German Silver	Wrought Iron to Mild Steel	Gold to Platinum	Wrought Iron to Cast Brass	Nickel Steel to Machine Steel
	Brass to Platinum	Steel to Platinum	Silver to Platinum	Wrought Iron to German Silver	

be made, Fig. 89, particularly for thin material. Heavy plates cannot be spot welded so readily as thin ones but they are frequently welded edge to edge, forming a butt weld, or a combination butt and

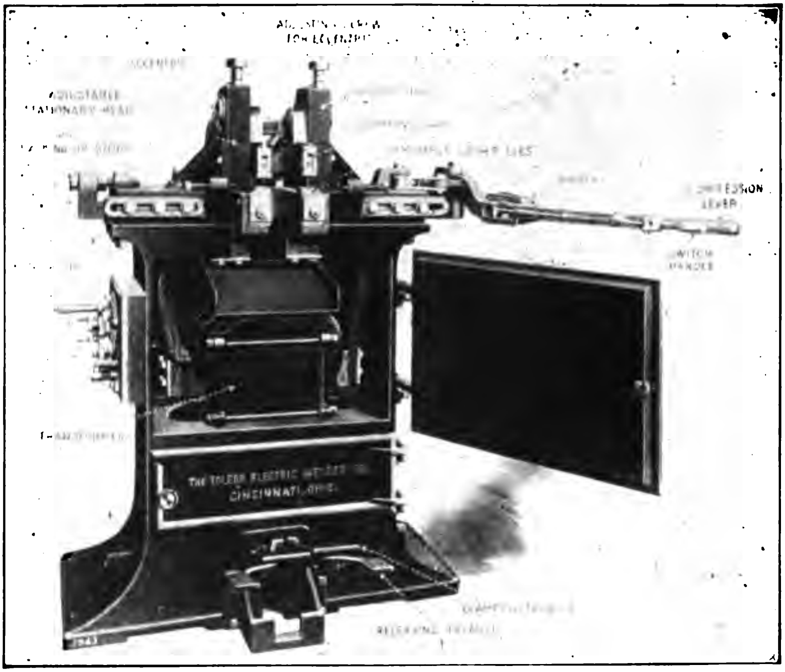


Fig. 91. Double Treadle Butt Welder
Courtesy of Toledo Electric Welder Company

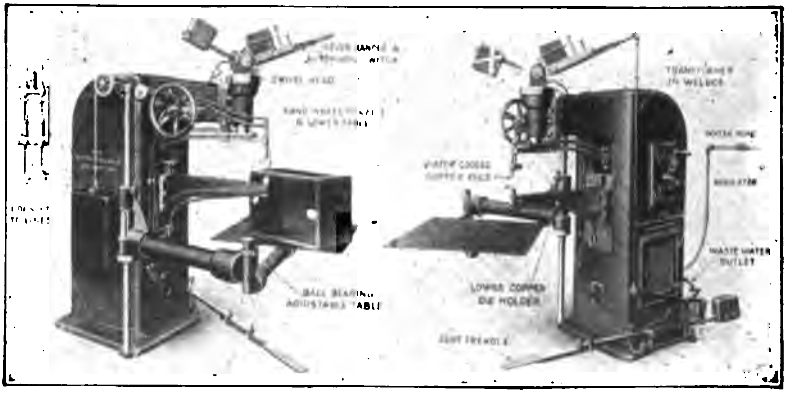


Fig. 92. Principal Parts of Spot Welder
Courtesy of Toledo Electric Welder Company

lap weld, as in Fig. 90. Special machines have been developed by the various manufacturers for numerous operations and for a wide range of articles, a few of which are shown in subsequent illustrations, and the work done with them is of the highest class. Practically every kind of metal can be welded by this process and many different kinds may be joined to each other, as shown in Table X. The great advantage of this process lies in the amount of work which can be done in a short time, but it is limited almost exclusively to the production of new articles instead of being also good for repair work like the arc system.

From a study of Table X it will be seen that practically all of the commercial combinations of metals can be made with butt or spot welding apparatus and, it may be added, there is no other system in use today that will do welding on as wide a range of metals, alloys, or combinations. This system operates on a very low voltage—about 3 volts—and the important factor, as with arc welding, is the amount of current.

Equipment Required. Butt or spot welding requires practically a separate machine for each class of work to be done, these machines consisting of a main frame, Figs. 91 and 92, containing a transformer and some means for clamping the article to be welded, together with a device for applying the pressure required to force the parts together when heated. Unless the machine is designed for one special sort of articles, it is necessary to have a reactive coil to adjust the current to suit the work and a switch to control this coil. As with any other electrical device, a main switch for connecting the welder to the power circuit is necessary, of course, and the larger sizes of machines are water cooled.

The illustrations scattered through the text of this section show the more important types of machines, and the pipes for carrying the cooling water to the copper contacts are clearly shown on most of them. These machines are built for welding pieces with cross sections as small as fine wires, Fig. 93, and as large as 7 or 8 square inches in section and may require as much as 200 horsepower for large work. Butt- or spot-welding machines can be operated from any single-phase power circuit supplying current at a constant voltage by providing the proper transformer, but direct current cannot be used.

Butt welders are comparatively low machines, Fig. 94, and have the clamps for the work on top, generally in the form of jaws with a lever for operating each pair, Fig. 95, and another lever or a hydraulic cylinder to bring the pieces together and to apply the required pressure when properly heated. The current is carried into the pieces through the jaws and is usually turned on auto-

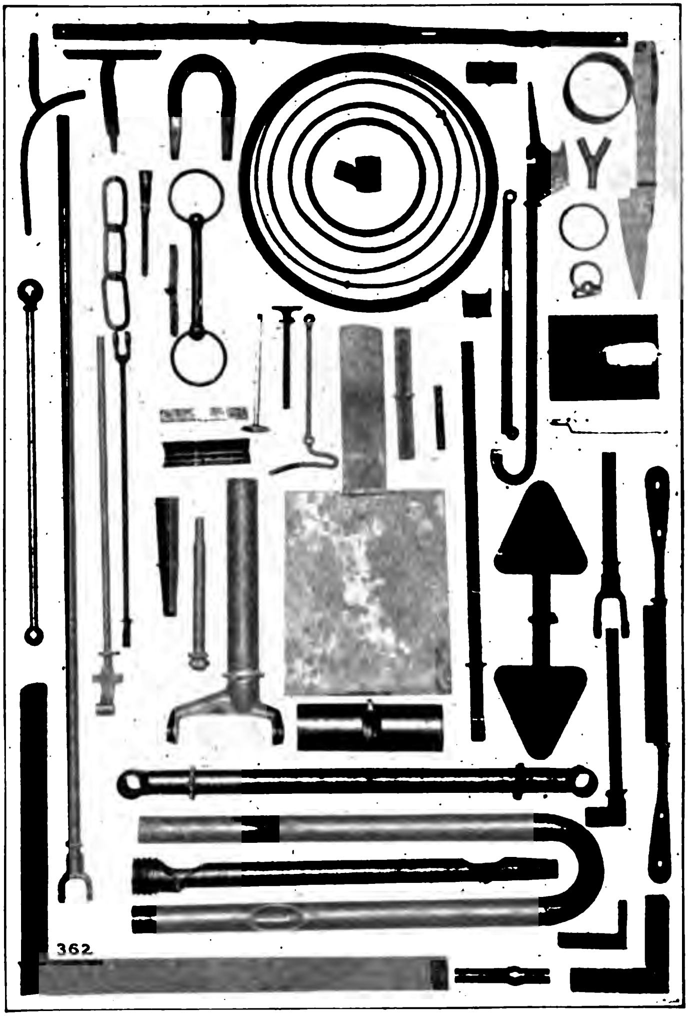


Fig. 93. Samples of Butt Welding
Courtesy of Toledo Electric Welder Company

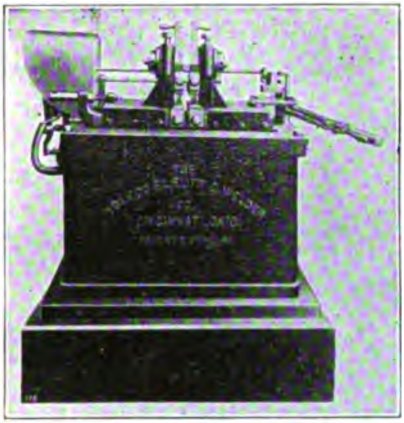


Fig. 94. Toledo Small Butt Welder

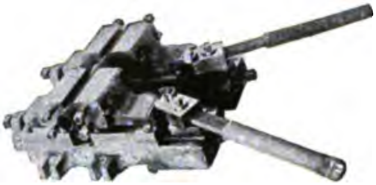


Fig. 95. Butt Welder Clamps for Pipes
Courtesy of Thomson Electric Welding Company

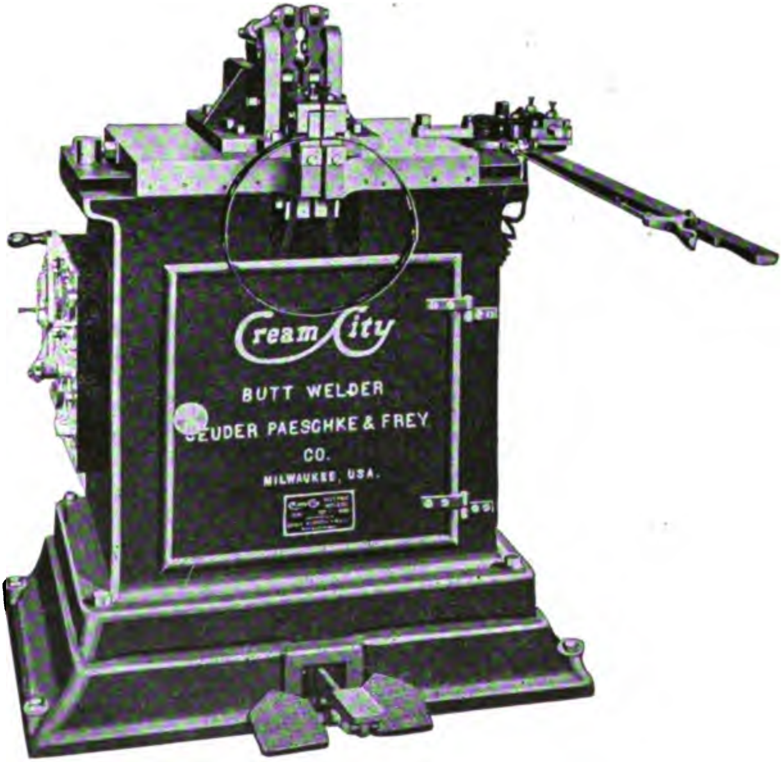


Fig. 96. Foot-Operated Butt Welder
Courtesy of Geuder, Paeschke, and Frey Company

matically after the parts are clamped into position. Foot levers are also provided on some forms of machines, Fig. 96, for clamping in order to leave the workman's hands free to handle the work. Spot welders, Figs. 97 and 98, are usually higher but smaller and

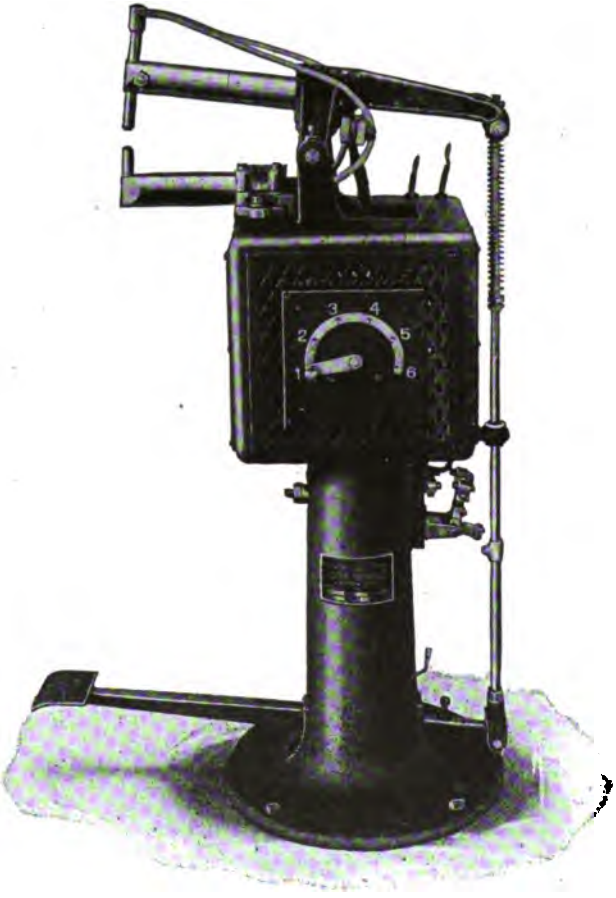


Fig. 97. Foot-Operated Spot Welder for Sheet Metal
Courtesy of Winfield Electric Welding Machine Company

have a pair of arms, Fig. 99, extending to one side for carrying the two welding tips or contacts; the pieces are laid together and placed on the lower contact and the upper one is forced down against it. The current is automatically switched on, when the contacts close, and the pressure is applied by a hand or a foot lever. Special machines are also made for rail welding, etc. (See Figs. 104 and 107.)

Source of Power. *A. C. City Circuits with Transformer.* The source of power for butt and spot welders should have the same general characteristics as for arc welding; that is, they should deliver the current at constant voltage regardless of load. In most places current can be purchased from a public service corporation and a transformer, to give current at the desired voltage, will be furnished to power users. City distribution circuits are usually operated at 2200 volts in order to reduce the amount of copper required for the lines and, since alternating current is required for butt and spot welding, it is easy to get current at proper voltage by using a

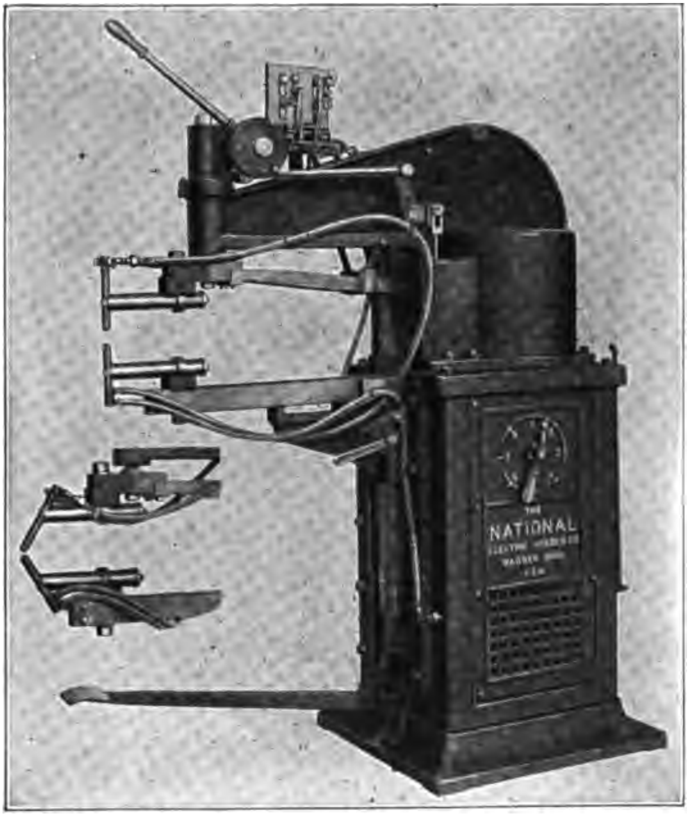


Fig. 98. 24-Inch Drop Arm Spot Welder Showing Different Positions of Universal Points
Courtesy of National Electric Welder Company

transformer. Most welders are provided with their own transformers wound to operate on a 220-volt circuit, although they can be made for use on any voltage up to 550 if necessary. Consequently, the line transformer should have a 220-volt secondary winding. The welding transformer will step the voltage down to the proper amount for welding and at the same time increase the current to the required amount. When it is necessary for the user of a welder to furnish his own power, it is best to use a motor-generator set, as such a machine will give better regulation than a rotary converter or a synchronous transformer. Engine-driven alternating-current generators may be used, if adequate means are provided to maintain constant speed under all conditions of load, and this is important for spot welders especially, because of the rapid and wide fluctuations of load in service.

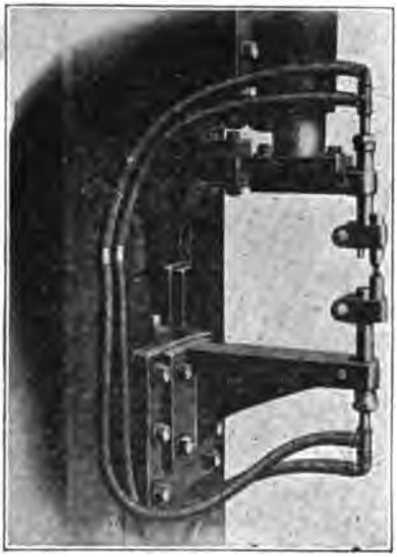


Fig. 99. Details of Spot Welder
Courtesy of Toledo Electric Welder Company

Transformer Requirements. The transformer does its work through magnetic action and entirely without moving parts. It consists of a laminated iron core, or body, with two sets of copper coils or windings so arranged that the alternating current in the line, or primary side, coils magnetises the iron core and sets up a magnetic field which causes current to flow in the welding, or secondary side, coils. The wires and number of turns in the two sets of coils are so proportioned that the secondary coils produce a high current at low voltage, when the primary coils are energized by a low current at high voltage. For most welding operations the voltage is from 3 to 5 volts, and the power required will vary from about 1 horsepower for small work up to 200 horsepower for large work. The power will vary inversely as the time required to make the weld, rapid work demanding more power than slow work.

PROCESSES OF WELDING BY RESISTANCE METHOD

Classification. The process of welding by the resistance method is the simplest of all methods of joining metals, and is also the quickest and cheapest method for work which may be easily handled. While it is true that it is limited almost exclusively to new work and to articles of moderate and small size, it is possible to do work in such quantity and of such variety that this system is used in numerous lines of production. The operation consists mainly in clamping the pieces in the machine, passing the current through the point of contact until it heats, and then squeezing the pieces together until they join. At the proper temperature, the metal will be in a plastic state and the molecules of the two pieces will amalgamate, or mix, so as to unite and form one piece. If the pieces are of different metals, the result will be an alloy of the two metals at the joint. When the nature of the metal is such that it is injured at high temperatures—as, for instance, brass or tool steel—it should be heated quickly and pushed together hard enough to squeeze the burnt metal out of the weld. Experience will soon show the correct heat for the best results on each metal, but the makers of the various welders will be glad to state the proper current, time, and temperature for any sort of work.

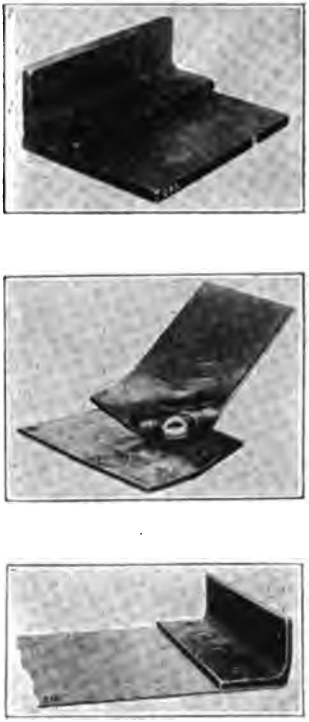


Fig. 100. Examples of Spot-Welded Joints
Courtesy of Toledo Electric Welder Company

Butt welding, as its name indicates, is the operation of welding two pieces of metal end to end or side to side, and spot welding is the operation of welding two pieces by lapping them and welding them in spots only, Fig. 100, instead of full width as with butt welding. Numerous modifications of both these processes have been developed for special shapes and sizes of pieces, among which may be mentioned lap welding, tee welding, cross welding, seam welding, upsetting, jump welding, annealing, and brazing. The two latter applications of resistance-welding machines are not welding in the true sense but are practical applications of the apparatus, which should be understood. Hardening and tempering may also be done through the use of this apparatus and rivet heads, heated ready for shaping, can easily be formed by pressure. Light or small work can be done on large machines, of course, but not very economically, and large work can be done on small machines but it is a dangerous practice on account of the excessive current required and should be discouraged.

Butt Welding. Butt welding is applicable to welding metals of practically the same cross section by bringing them together end to end or edge to edge; all of the energy passing through the joint is effective because it is confined to a limited area of contact. A slight projection or fin will be raised at the joint, Fig. 88, due to the flowing of the soft metal, but this is easily removed.

Spot Welding. Spot welding is the operation of joining sheets by heating and softening the metal in spots only, each about the size of a rivet, and applying pressure while the metal is plastic. The operation causes a slight thinning of the metal at the weld, No. 3, Fig. 89, due to the pressure, but when it is properly done the joint should be as strong as the rest of the sheet.

Lap Welding. Lap welding consists in making a joint by overlapping the edges of the sheets to be welded, heating the joint, and applying pressure by means of rolls which pass along the seam. This makes a continuous seam, instead of merely a series of spots, and gives a tighter and stronger joint than spot welding. It is used to a lesser degree than either of the other methods, but is coming into more general use for special purposes such as welding-in barrel heads, making grease cans, oil tanks, etc. Seam welding is a similar operation.

Butt Seam Welding. Butt seam welding is an operation similar to ordinary butt welding in one respect and like lap welding in another. It is used for making the seam in steel plate articles of moderate thicknesses, such as range boilers; it is done in a machine which brings the edges of the plates together and does the welding by pressure while hot, in the usual manner, Fig. 101. The special feature of the machine lies in the fact that the current is carried into the plates and across the seam by means of rolls each side of the joint. As the work progresses through the machine, the rolls keep the current always passing across the joint just ahead of where the pressure is applied.

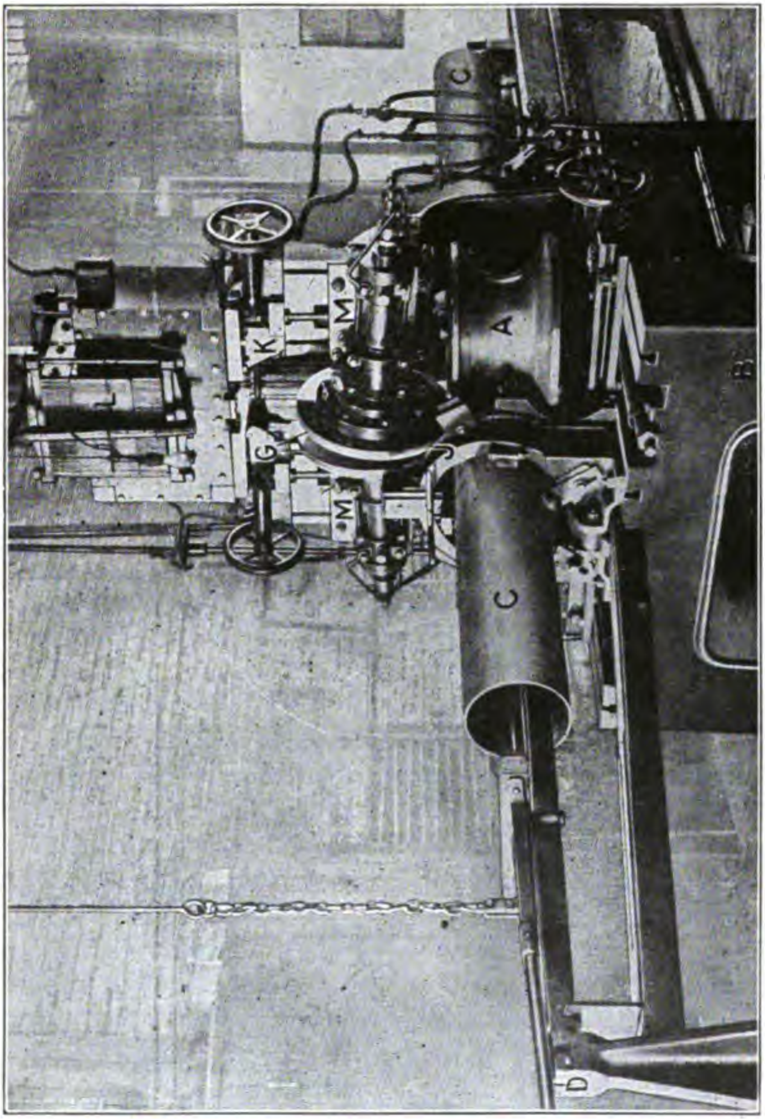


Fig. 101. Electric Welding Machine for Tubes with Tube in Position

Tee Welding. Tee welding is the process of making a weld in the shape of a "T" by welding one piece to the side of another. The peculiar feature of this process is that the head of the tee must be heated first in order that the shank may not be burned before the parts are both soft enough to weld.

Jump Welding. Jump welding is similar to tee welding and is used on light stock which does not require preheating before welding. This process is also used for pipe work, when forming tees or welding branches into larger pipes, and the hole in the header or main pipe should be made before welding the branch.

Cross Welding. Cross welding is done when forming wires or bars into screens or when making any other article requiring the crossing of strips. The pieces are merely laid together and a welded joint formed at the crossing in either a butt-or a spot-welding machine. The pieces will flatten at the joint, of course.

Upsetting. Upsetting is the operation of forming an enlarged section on a bar for the purpose of increasing its strength or for reforming it to another shape. The bar is placed between the jaws of a butt welder, the current passed through the space to be upset, and pressure applied when the bar heats. The pressure will squeeze the metal up so that the bar will expand, after which it may be hammered into the desired shape while hot. This process must be distinguished from ordinary butt welding in which the joint swells and shows an "upset". Deliberate "upsetting" is usually carried much further. A "flash weld" is a similar operation and is used on wide stock or on rectangular pieces and when ever the ends of the stock cannot be trimmed square. It consists in squeezing the metal so hard and rapidly while soft that it almost "squirts" apart and forms feathery fins around the joint which must be ground off. It is used when welding brass and copper and an amount equal to the diameter or thickness of the material is taken up in the weld.

Electric Annealing. Electric annealing can be done with either a butt welder or a spot welder and consists in passing the current through the part to be annealed, heating it until soft, and allowing it to cool slowly. Hardened steel plates, springs, dies, tools, chilled rolls, etc., may be treated this way and may then be drilled or cut very readily. When much of this work is to be done, it is better to have a special machine made for the article because it will reduce the cost.

Hardening and Tempering. Hardening and tempering can also be done by heating the pieces in a butt welding machine and, when the desired color is reached, chilling in the usual manner. The advantage in this process lies in the fact that the work is always in sight.

Electric Brazing. Electric brazing can be done quickly by placing the parts in a butt- or seam-welding machine, heating the joint, and then applying the spelter and flux, allowing them to run into the joint. The temperature can be controlled more easily than by any other process and the work is always in sight. It would seem, however, that welding would be preferable to brazing.

Electric Riveting. Electric riveting is another recent variation of the spot-welding process and consists in making the holes in the pieces, inserting the rivets, heating them between the tips of a spot welder, and then pressing them to form heads while soft. It is very quickly done and eliminates the rivet heating furnace; for heavy work it is good, but is more expensive than straight spot welding for thin plates.

General Matters of Good Practice. *Freedom from Dirt and Grease.* When doing either butt or spot welding or any of their variations, it is important to see that the surfaces are cleaned thoroughly before starting to weld them because the presence of grease, dirt, or other matter between the surfaces will prevent a perfect joint. The cleaner and better the stock the easier it is to weld, the less current it takes, and the less wear on the dies. Dirt, grease, and scale are insulators, in most cases, and it takes only a small amount, at the low voltage used, to prevent the flow of current; if there is any undue heating in any part of the machine where there,

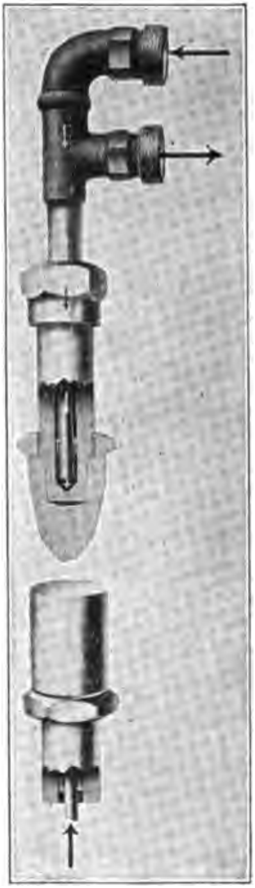


Fig. 102. Water-Cooled Die Point
Courtesy of Toledo Electric Welder Company

is a joint in the circuit, it should be carefully examined for dirt and grease and then cleaned. Bolts frequently work loose and, allowing oil to carry dirt under their heads, cause heating. There is no danger of a shock from the welding circuit because of the low voltage but

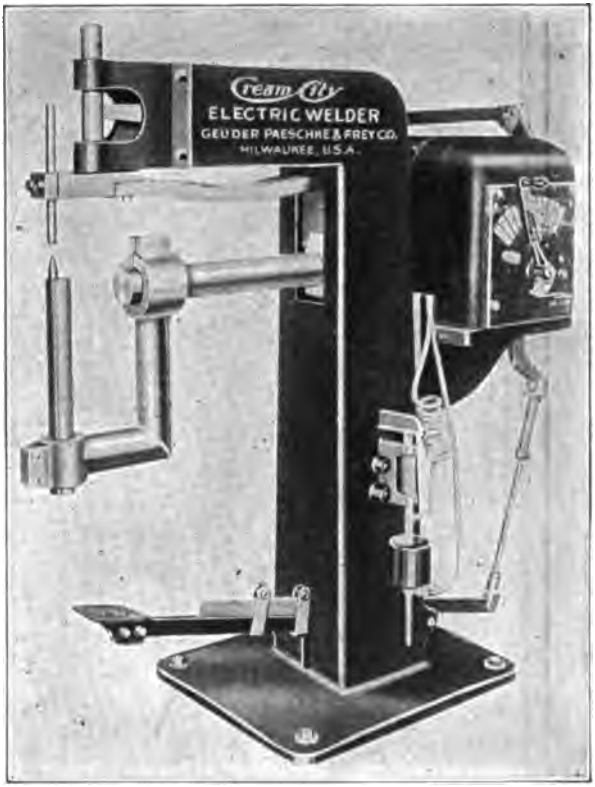


Fig. 103. Spot Welder Showing Simple Construction
Courtesy of Geuder, Paeschke and Frey Company

the line, or primary side of the machine, should be avoided, if possible or handled with proper precaution.

Avoiding Heating of Parts. If the machine has been properly installed, there should be no trouble so long as the cooling water flows through the welding dies, Fig. 102, and everything is kept clean and all connections tight. The only moving parts on most contact welders are the clamps and jaws, Fig. 103, and these are easily watched; the transformer is so simple it should never get out of order except in cases of accident. The switches should be enclosed to prevent accidental contact and ordinarily are automatic and out of reach.

APPLICATIONS TO MANUFACTURE

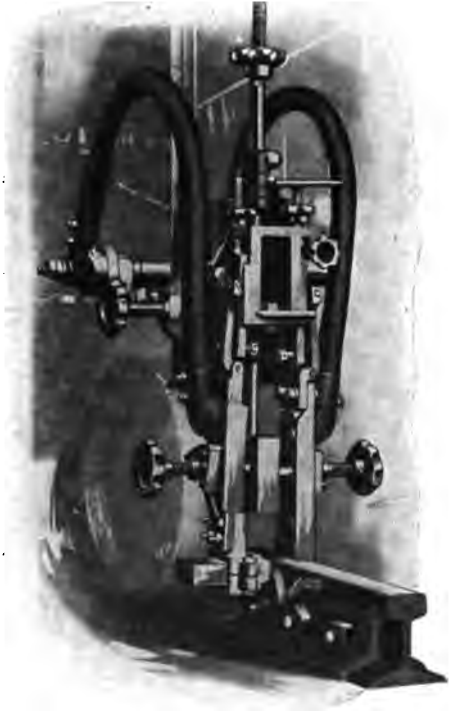


Fig. 104. Spot Welder for Bonding Rails
Courtesy of Electric Railway Improvement Company

General Applications. The applications of welding by this process are too numerous to mention here, but some of the more important ones are in the manufacture of wagon tires, axles, iron wheels, bicycle parts, pedals, brake parts, chain adjusters, tools, shovels, printers rolls, wire and strip hoops, screens, special piping, rail bonding, as shown in Figs. 104 and 105, rings and chains, automobile parts, steering knuckles and rods, step brackets, valve heads and stems, typewriter bars, sheaves and pulleys, umbrella rods, frames, Fig. 106, structural iron work, stovepipe, knives, steel enamelled ware, etc. Practically every kind of metal can be welded and every shape or section that can be put into the machine can be manipulated if the surfaces can be brought together. Special machines for welding the joints in track rails have been devised and Fig. 107 shows the cars and other details of the equipment required.

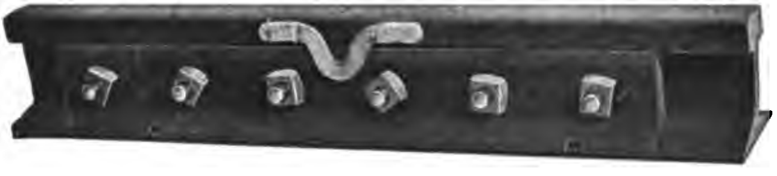


Fig. 105. Bonded Rail
Courtesy of Electric Railway Improvement Company

A large spot welder, the details of which are shown in Fig. 108. is used and is made so that the jaws hang vertically down from a crane, with a transformer suspended between them. Pressure is applied through a hydraulic cylinder and plates are welded to each side of the web of the rail. The top of the rails is ground smooth after welding.

When welding hoops, Fig. 96, the strip is bent around and the ends

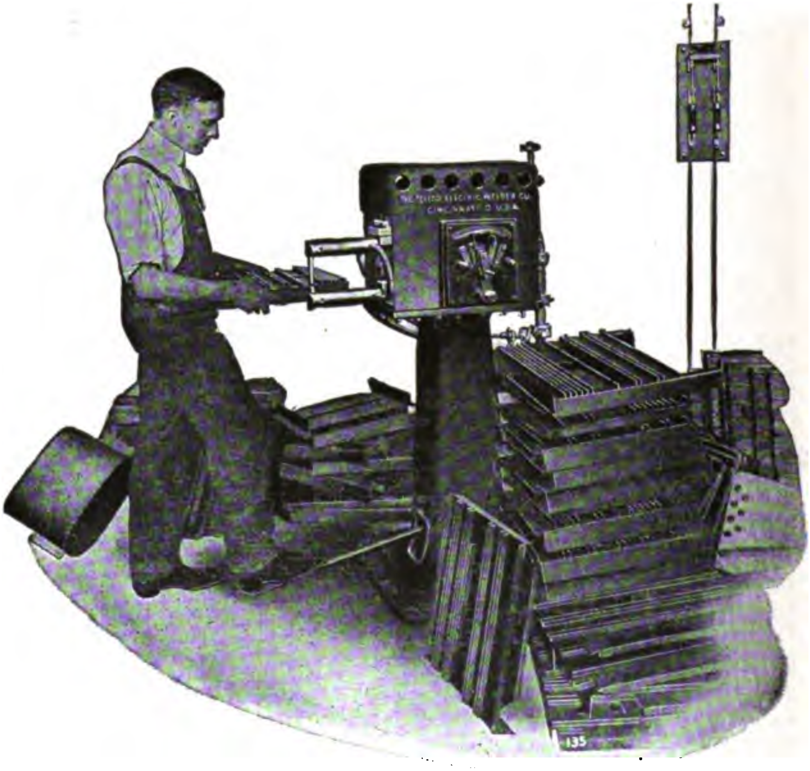


Fig. 106. Spot Welder for Pressed Metal Frames
Courtesy of Toledo Electric Welder Company

brought together and clamped in the jaws of a butt welder. Most of the current will cross the joint, because the jaws are set close and the path across the joint offers the least resistance, although a part of the current will go around the hoop. Chains are welded in the same manner, Fig. 109, and the work is successful in spite of the short length of circuit around the link. Automatic machines are sometimes used for chain making, wire fencing, screens, and other articles requiring a repetition of numerous simple joints, Fig. 110. Sheet steel and aluminum automobile bodies, mud guards, bonnets, and other parts are spot welded. Coffeepots, Fig. 111, kettles, and similar articles have their spouts and handles spot welded on, and coal pails, wheelbarrow bodies, spiral piping, coal chutes, boxes, cabinets, lockers, steel shelving, and hundreds of other articles offer almost unlimited opportunities for welding by this system. Butt welding is used to almost as great an extent as blacksmith welding and is much cheaper.

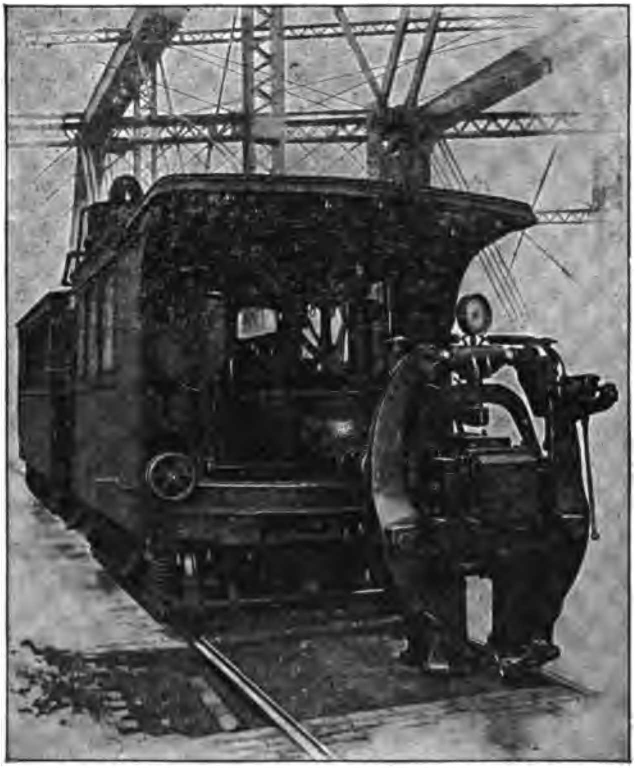


Fig. 107. Electric Rail Welder and Car
Courtesy of Lorain Steel Company, Johnstown, Pennsylvania

Practice with Different Metals. *Iron and Steel.* Iron and steel are used more than any other metals and are, therefore, the metals most commonly welded by all processes; fortunately they are about the easiest to weld. For butt-welding iron or steel the stock should be clamped in the dies with comparatively little projection and the ends brought together before switching on the current. Considerable pressure is required because it is better to keep the temperature below the melting point. For an upset weld the dies should be about 1 inch apart and for a flash weld they should be about ¼ inch apart for ordinary sections.

Cast Iron. Cast iron cannot be welded commercially by this process because of its crystalline structure and the high percentages of carbon and silicon in its composition. The arc-welding process is the one to use for cast iron, as the metal passes readily from the crystalline to the fluid state when sufficiently heated, which is a disadvantage for butt or spot welding.

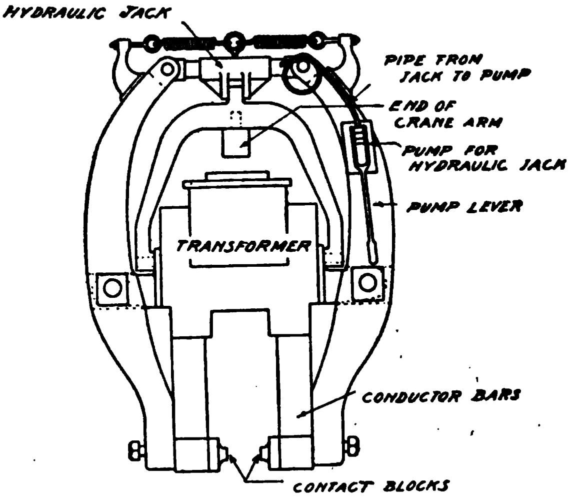


Fig. 108. Diagram of Lorain Rail Welder

High Carbon Steel. High carbon steel can be welded by this process but must be annealed afterwards to relieve the stresses set up by the localized heating. A good joint can always be made with steel of .25 per cent carbon or less, frequently with steel containing up to .75 per cent carbon, but seldom with that containing more than .75 per cent. It requires an experienced operator to get good results with high carbon steel because it is so easily injured. High and low carbon steels can be welded together successfully by good operators, if the low carbon stock is allowed to project further through its die than the high carbon steel.

Nickel Steel. Nickel steel may be welded readily and the strength is high.

Copper and Brass. Copper and brass may be welded and have the joint strong enough to stand the strain of redrawing through dies but the pressure, when welding, must be less than for iron.

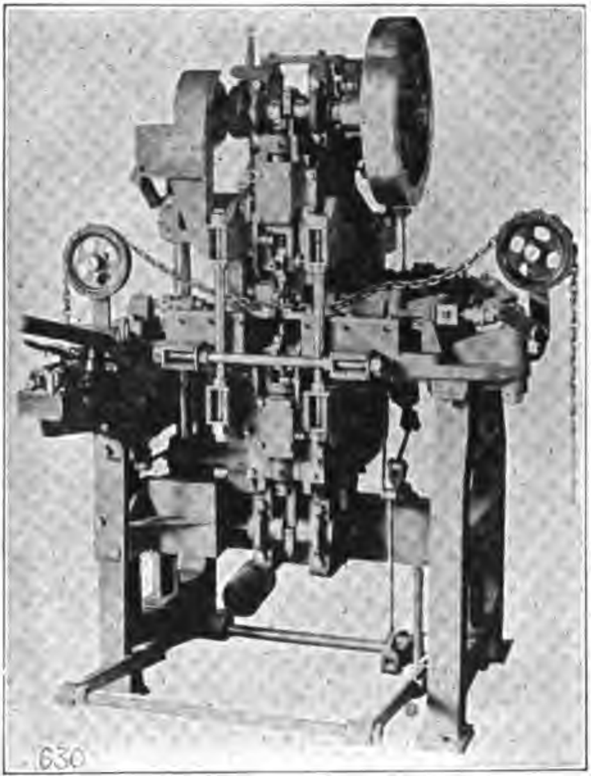


Fig. 109. Semi-Automatic Chain Welder
Courtesy of Thomson Electric Welding Company

The metal is really allowed to fuse, or melt, at the joint and the pressure should be just sufficient to force out the burnt metal. It is because of this that good welds are possible, but the current must be shut off as soon as the ends of the pieces soften, and an automatic switch is provided for this on some machines. The dies should be set apart 3 or 4 times the thickness of the stock and more current should be used than for iron.

Iron and Copper. Iron and copper can be welded together, if the section of the copper is less than the iron at the point of contact, as the former is a better conductor.

Galvanized Iron. Galvanized iron of No. 22 gage and heavier can be spot-welded but it will burn the zinc off at the welded spot and on both sides of the sheets. For thinner sheets it does not pay to try welding by this method.

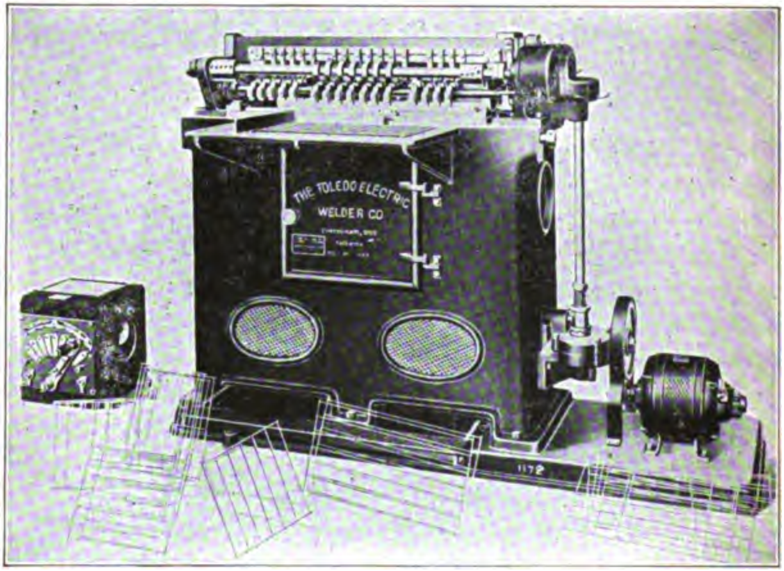


Fig. 110. Electric Welder Capable of Welding Sixteen Wires at One Time
Courtesy of Toledo Electric Welder Company

Sheet Brass. Sheet brass can be welded to brass or to sheet steel after sufficient experimenting to determine the proper heat and pressure.

Sheet Aluminum. Sheet aluminum of some grades can be spot-welded but the surface will be rough and pitted where the die points touch it.

Sheet Copper. Sheet copper is hard to weld because of its low resistance, but it can be done by an experienced operator using sufficient current.

TABLE XI

Power and Time for Butt Welding

IRON AND STEEL				BRASS				COPPER			
Area Sq. In.	Power Kw.	Seconds	H. P.	Area Sq. In.	Power Kw.	Seconds	H. P.	Area Sq. In.	Power Kw.	Seconds	H. P.
.25	6.	20	8.	.125	6.	10	8.	.0625	5.	5	7.
.50	10.	28	13.5	.25	12.	14	15.7	.125	8.5	7	11.5
.75	13.	35	17.5	.375	12.6	17	17.	.1875	12.	9	16.
1.00	18.75	40	25.	.50	15.	20	20.	.250	18.	10	24.0
1.50	29.5	44	39.5	.75	25.	22	33.5	.375	28.5	11	38.
2.00	33.	57	44.0	1.00	29.5	28	39.5	.500	32.	14	43.
2.50	38.	63	50.	1.25	37.	32	50.	.625	37.	16	50.
3.00	43.5	70	58.5	1.50	43.	35	52.7	.75	43.	18	52.
4.00	56.3	80	76.	2.00	53.	40	71.	1.00	55.5	20	75.
5.00	61.7	90	83.	2.50	60.	45	80.	1.25	61.	23	82.
6.00	69.	98	92.5	3.00	66.	49	88.5	1.50	68.	25	91.

Limits as to Thickness of Metal. There is a limit to the thickness of sheets which can be spot-welded and to the sectional area of pieces which can be butt-welded because of the heating of the dies or clamps by the large amounts of current required for heavy work. If enough cooling water is passed through the dies to prevent overheating, it will also carry off some of the heat from the work and a point is soon reached where the area of contact of the dies becomes so great as to be a disadvantage. Theoretically, it is possible to weld any size section with a comparatively small current by leaving it on long enough, but in practice we must take radiation into account, for a point is soon reached where radiation equals the heating effect of the current and, at this point, the temperature remains constant.

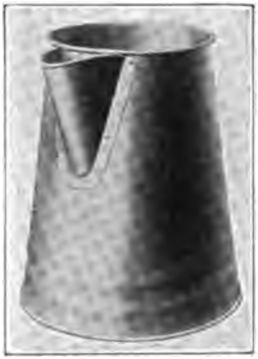


Fig. 111. Coffee Pot with Spot-Welded Spout

Power Required. The power required for butt and spot welding is easily determined from the cross section and material of the piece, because considerable experimental data is available. As previously stated, the power required for this kind of welding varies inversely as the time consumed in making the weld. This means that the longer you can take to do the work, the less current you will require; and the quicker you wish to accomplish the work, the more

TABLE XII

Butt Welder Data

Rd. Iron Diameter in inches	Area in Square Inches	Kw. Required	H. P. at Dynamo	Time in Seconds to Make Weld	Cost per 1000 Welds at 1 cent per Kw.
¼	.05	2	3	3	0.02
⅜	.11	3.5	5	5	.05
½	.20	5	7.5	5	.07
⅝	.31	7.5	12	10	.21
¾	.44	12	17	15	.50
⅞	.60	15	22	18	.75
1	.79	18	25	20	1.00
1⅛	.99	25	35	25	1.73
1¼	1.23	35	50	30	2.90
1½	1.77	50	70	40	5.55
1¾	2.41	65	85	45	8.12
2	3.14	75	100	50	10.42

As the rate charged for current varies in different places, we have figured the current at one cent per Kw. hour to give a basis for calculating the cost. Multiply the prices given above by the rate per Kw. hour charged by your local electric light company, and that will give your cost for current for 1000 welds.

current you must use. The total amount of energy in kilowatt hours will be the same in either case, but a larger transformer must be used for rapid work.

Tables XI, XII, and XIII will give a good idea of the power and time required for various thicknesses of metal with butt welding and spot welding, and it will be well to compare the effect of time on the current used.

Table XII is different from Table XI for similar sizes of section because of the difference in the time taken per weld.

Table XII is based only on the use of iron rods, the diameters being given in Column I. Table XIII is based upon steel, but in the form of sheets. The costs of making the welds as given in Tables XII and XIII are very interesting and should be carefully noted.

Cost of Butt and Spot Welding. The cost of welding by both butt and spot methods can easily be figured from tables XII and XIII by determining the cost of current for the operating conditions under consideration and adding the required amount for labor and overhead charges in the shops. The latter item is very important and will have a noticeable influence on the cost of welding in most shops. The labor for handling the material to and from the

TABLE XIII

Spot Welder Data

Gages of Sheet Steel	Thickness in Fractions of an Inch	Thickness in Decimal Parts of an Inch	Approximate Kw. Capacity	H. P. at Dymano	Time in Seconds to Make a Weld	Cost per 1000 Welds at 1 Cent per Kw.
28	1-64	.015625	5	8	.3	.0045
26	3-160	.01875	6	9	.4	.0065
24	1-40	.025	7	11	.5	.01
22	1-32	.03125	8	13	.6	.0135
20	3-80	.0375	9	14	.7	.0175
18	1-20	.05	10	15	.8	.0225
16	1-16	.0625	12	18	.9	.030
14	5-64	.078125	14	20	1.	.039
12	7-64	.109375	16	23	1.3	.058
10	9-64	.140625	18	25	1.5	.075
9	5-32	.15625	20	30	2.	.112
8	11-64	.17187	23	34	2.5	.16
7	3-16	.1875	25	37	3.	.21
6	13-64	.20312	28	42	4.	.31
5	7-32	.21875	30	45	5.	.42
4	15-64	.23437	33	48	6.	.55
3	1-4	.25	35	53	7.	.68

Based on using fairly clean stock, this table will give an idea of the time and current required in welding different gages of sheet steel.

As the rate charged for current varies in different places, the current has been figured at one cent per kw. hour to give a basis for calculating the cost. Multiply the prices given above by the rate per kw. hour charged by the local electric light company, and that will give the cost for current for 1000 welds in any given locality.

welding machine is just as important as that of the operator himself, and the cost of such labor, together with the interest and depreciation on the purchase price of the welding machine and the cost of installing, are part of the overhead expense. Articles of special shapes will require different amounts of current and experiment alone will show the current required; this factor, with the labor and overhead expenses, will give the cost. It will be self-evident that the better provision one makes for handling the work, the lower will be the cost per unit produced.

Strength of the Weld. The strength of the weld should equal from 75 per cent of the original material on heavy stock up to 95 per cent of it on light stock, when finished to the same diameter or thickness as the piece; this can be made 100 per cent or greater, if a reinforcement can be left on in the form of an upset. The strength of a weld is slightly increased by working after welding, unless there is too much carbon or silicon in the iron. The metal is not damaged by welding with either the butt- or spot-welding systems, if properly done, because the heat can be controlled so exactly. The oxide which may be present at the joint is usually forced out into the upset and ground off; so a burned weld is a rare thing with this system. In the early days of the Thomson system, there were complaints of weak spongy burnt welds, when made by butt welding, but this was largely due to inexperience and the tendency to heat the metal too much. If an excess of heat is applied, either by using too high a current or leaving it on too long, the metal may be weakened within the heating radius and break about an inch from the joint.

Watertown Arsenal Tests. A number of years ago, a series of tests on electric welding was conducted at the Watertown Arsenal, and the following results were reported in the *Transactions of the American Society of Mechanical Engineers* for 1898:

> Wrought-iron welds averaged from 5 per cent to 10 per cent below that of the plain bars and the fractures were either fibrous or slightly spongy.
>
> Steel welds showed a strength of only from 20 per cent to 50 per cent of the original.
>
> Steel welded to wrought iron showed a strength equal to the iron.
>
> Copper showed a strength of from 90 per cent to 95 per cent of the original stock.
>
> Brass and wrought iron gave very uncertain welds and low strength.

Out of sixty samples welded, twenty-nine broke in the weld; seventeen, within two inches of the weld; eleven, within the range of moderate heat; and two broke near the grips of the testing machine. Some of the steel welds were almost as strong as the bars and some of the iron welds were of slightly greater strength than the bars; so it will be seen that welding by this system compares very favorably with other methods of welding.

Manufacturers of Butt and Spot Welders. There are several firms making butt- and spot-welding apparatus in this country today and it will pay the student to get data from all of them. The principal companies are the Thomson Electric Welding Company, Lynn, Mass.; Geuder, Paeschke & Frey, Milwaukee, Wisconsin; National Electric Welder Company, Warren, Ohio; Toledo Electric

Welder Company, Cincinnati, Ohio; and Winfield Electric Welding Machine Company, Warren, Ohio. All of these makers have certain forms of machines which are adapted to particular lines of products, and they also manufacture other types, designed for any special service for which machines operating under this system of welding are capable.

GAS WELDING AND CUTTING

General Features of Method. Hot-flame, or gas, welding and cutting has been a practical process for so long that there is no very clear record as to just when it first came into commercial use, but the development and exploitation of apparatus for the generation and use of gases for welding during the past ten or fifteen years has given an added impetus to the art and it is now used in many ways which were not originally contemplated. The process of gas welding consists merely in joining metals by fusing them together at the point desired through the use of a high temperature gas flame as the source of heat. Various gases and combinations of gases are used and several types of apparatus are now on the market for the purpose. Cutting by the flame is a later development than welding and is both rapid and economical.

Defining Terms. There are two methods of welding in general use, the "Autogenous" and the "Heterogeneous", the names indicating clearly the main difference. The word "autogenous" signifies that the weld is made by the fusion or junction of the articles themselves, without the use of outside filling material to complete the joint. The word "heterogeneous" means a mixture, and signifies that the weld is made by fusing-in some sort of additional filling material, instead of depending entirely upon the metal of the pieces themselves. It is obvious that, if the filling material is of a metal different from the pieces welded, we still have heterogeneous welding; so this name can be correctly applied to brazing or soldering. Custom makes laws, it is said, and custom limits the term "welding" to cases where the same metal is used for a filler as is used in the article welded, and that is the way the term used here. The term "autogenous" has unfortunately come to be applied to all forms of gas welding, and some confusion has resulted because the statement is made that neither flux nor hammering is necessary with that process. The truth is that fluxes are very beneficial when welding some metals and hammering helps the strength of welds in heavy pieces because it tends to change the structure of the metal from a crystalline to a fibrous nature. Further reference will be made to this later, when discussing methods of welding.

Combinations of Gases with Oxygen. The gases originally used for welding were probably oxygen and hydrogen, and efforts to liquefy them were made about one hundred years ago in order to simplify the means of storing them. It took about fifty years to develop a good process for doing this and resulted in the development of one of the principal present-day methods of producing oxygen. Most of the welding today is done with systems using oxygen in combination with another gas; and the processes take their names from the gases used. The leading processes are known as the oxy-acetylene, oxy-hydrogen (or oxy-hydric), oxy-pintsch gas, blau-gas, water-gas and coal-gas welding processes, the oxy-pintsch-gas process being the latest development. All of these processes depend upon the use of compressed gases, usually stored in strong cylinders and mixed in a burner or torch as used, and may be used for either cutting or welding.

Advantages Claimed. The principal advantages claimed for gas welding are: the simplicity of the process; low first cost of the apparatus; wide range of applicability; light weight of the parts; ease of portability, if necessary; high temperature of the flame; and flexibility of the process for heating purposes. The limitations of the process are: the danger from using an exposed flame; the liability of explosion of the gas tanks and generators; oxidation or carbonization of the weld by the flame; crystallization and cracking of the weld when cooling; and high cost of operation as compared with electric welding. The danger from explosions is being reduced gradually by improved apparatus and the restrictions imposed by the Board of Fire Underwriters.

In manufacturing plants and large repair shops, stationary plants for the generation of acetylene are generally used and the oxygen is purchased from companies making it on a large scale, but some of the larger concerns also make their own oxygen. The same rule applies to the gases used for other processes of welding than the oxy-acetylene. Small portable outfits are also made for moving about shops which do comparatively little welding, tanks of gas of the proper kind being mounted on substantial trucks. In a few cases small gas generators are mounted on the trucks, but these offer but little advantage over the tanks and are more expensive and harder to handle.

GASES USED FOR WELDING

Gases and their sources form a very important part of the study of the gas-welding processes, because a knowledge of these will often be of great value in determining the best process for particular purposes. This is becoming more necessary because so many concerns are installing their own generating plants in order to get their gases cheaper and more promptly than is otherwise possible. The gases used in hot-flame welding today are acetylene, blau gas, coal gas, hydrogen, oxygen, pintsch gas, and water gas, and various methods are in use for their production and storage.

About one hundred years ago, considerable experimenting was done by the leading physicists to determine the best methods of obtaining the various gases on a commercial scale, and to discover how they might be compressed or even liquefied, with the result that many of the gases in use today for welding were produced on a commercial scale and their value for heating purposes demonstrated, many years ago.

Acetylene (C_2H_2). Acetylene is a colorless gas with a very disagreeable odor, very largely due to the impurities present. It was first obtained by Davy in 1837 when making potassium. Berthelot produced acetylene in 1858 by passing hydrogen through an electric arc, and Wohler produced calcium carbide in 1862 by fusing lime, zinc, and carbon together and then obtained acetylene by adding water to the carbide. Acetylene was first liquefied by Cailletet in 1877 and the use of compressed acetylene was developed by Claude and Hesse. Today, acetylene is obtained almost exclusively from calcium carbide and water, and great care must be exercised to see that pure carbide is used in order to prevent the generation of phosphureted hydrogen along with the acetylene.

Calcium Carbide (CaC_2). Calcium carbide is a dark gray slag formed by fusing lime and coke in the intense heat of an electric furnace; it possesses a great affinity for water. When calcium carbide is combined with water (H_2O), in the proportion of 2 parts water to 1 part carbide, a chemical reaction takes place which heats the mass and forms acetylene (C_2H_2) and lime ($CaOH_2O$) in the form of ashes. In other words, the carbon combines with the hydrogen to form acetylene and the calcium combines with the oxygen to form lime. One pound of carbide will yield about 4½ cubic feet of acetylene.

Calcium carbide alone is not an explosive and it will not explode even when exposed to the highest heat but, unless it is kept dry, it will absorb moisture and generate acetylene, which is explosive. This is why it is best to store calcium carbide in air-tight tins.

Methods of Storing Acetylene. When mixed with air, acetylene is explosive over a long range of proportions and this makes the gas very troublesome. It is explosive over the limits of 2 per cent gas and 98 per cent air up to 49 per cent gas and 51 per cent air and, when mixed with oxygen, it burns with a tremendous heat. Acetylene dissociates at 780 degrees centigrade into carbon and hydrogen and, when under a pressure of two atmospheres (30 pounds) or more, it is tricky and liable to explode; so it is sometimes stored in specially prepared tanks. Acetylene is readily soluble in liquid acetone, which is cheap, inert, and incombustible; so storage cylinders or tanks are filled partly full of it and then the acetylene gas is compressed into it. Acetone at atmospheric pressure and a temperature of 15 degrees centigrade will dissolve 24 times its own volume of acetylene and, at 12 times atmospheric pressure (180 pounds), it will dissolve about 300 times its volume of acetylene and expand about 50 per cent. The cylinders are partly filled with asbestos fiber to carry the acetone and, to fill the cylinder, it is merely necessary to charge it with compressed acetylene. The various types of acetylene generators will be described later.

Blau Gas. Blau gas is liquefied illuminating gas and is produced by the distillation of mineral oils in red-hot retorts. It contains the same elements as ordinary coal gas but in different proportions; it is free from carbon oxide and is therefore not poisonous. It contains carbon and hydrogen in the proportion of about 5 parts of carbon to 1 part hydrogen and will develop about 20 per cent more heat units than acetylene. Blau gas, named after its inventor, can be compressed and liquefied; when liquefied it occupies but 1/400 part of its gaseous volume and is usually sold under a pressure of

100 atmospheres, in steel cylinders. It is very inert and therefore difficult to explode, the range of explosiveness being from 4 per cent gas and 96 per cent air up to only 8 per cent gas and 92 per cent air. This gas is already used quite extensively abroad, and is beginning to be used more and more in this country.

Coal Gas. Coal gas, or illuminating gas, is produced by the destructive distillation of coal and its discovery dates back to 1727. It is made by heating coal to the point where it decomposes in a closed retort in order that the gas, tar, and other constituents may be saved. Bituminous coal is better for gas making than anthracite because it softens or fuses at a temperature much lower than that required for combustion and this fusion is the commencement of the destructive distillation which forms the solid, liquid, and gaseous compounds from the coal. The operation takes place in specially constructed furnaces and the gas is carried to storage tanks after being washed to remove impurities. One ton of coal will produce about 10,000 cubic feet of gas, 1400 pounds of coke, 12 gallons of tar, and 4 pounds of ammonia, the operation lasting about 4 hours. The gas contains about 5 per cent of hydrocarbon vapors, 13 per cent of carbon oxides, 31 per cent marsh gas, 46 per cent hydrogen, and 5 per cent nitrogen with traces of oxygen, and has a heat value of about 40 per cent that of acetylene. Its use for welding is limited to metals of low melting points and is gradually being superseded by other gases.

Hydrogen. Hydrogen is one of the elements and is the lightest substance known. It is obtained by the decomposition of water into oxygen and hydrogen, both gases being collected and used. Hydrogen is also prepared by passing steam over coke heated to a dull red. If the temperature is not too high, carbon dioxide and hydrogen will be formed ($C+2H_2O=2H_2+CO_2$) but the carbon dioxide may be removed by passing the gas through a vessel of slaked lime. Hydrogen may be liquefied and, when mixed with air or oxygen, is explosive. It is not poisonous but may cause death if inhaled because it will exclude oxygen from the lungs. When hydrogen and oxygen are mixed to form a gas in welding and cutting, they produce a temperature of about 2500 degrees centigrade.

Oxygen. Oxygen is the most important of all of the elements and is used as one of the gases in nearly all welding processes. It was discovered in 1774 by Priestley and Scheele, both working independently, and in 1789 Lavoisier proved that its presence was necessary for combustion in the air. Oxygen was liquefied in 1877 by Pictet at a pressure of 320 atmospheres.

Methods of Commercial Production. Oxygen is produced commercially by three methods: from the air by liquefaction and fractional distillation; from water by electrolytic action; and from potassium chlorate. The production of *oxygen from air by liquefaction* is by far the greatest source of this gas today for welding purposes, though electrolytic apparatus has recently been developed which is making a strong competitor where power is cheap. The oxygen used for welding must be free from chlorine, although the usual mixture of 5 per cent of nitrogen and from 2 to 3 per cent of hydrogen is no disadvantage. Its production is not a very complicated process, but the apparatus is rather expensive, and only those plants requiring 1000 feet or more per week can afford to make their own gas.

The principal process for producing oxygen from the air is that developed by Linde and consists in liquefying the air and separating the nitrogen and oxygen by fractional distillation, similar to rectifying spirits. The air is first compressed to 1800 pounds per square-inch pressure, and cooled by ice and salt, or ammonia. When the air is compressed, as stated, its temperature rises because of the compression and must be cooled before the compression is continued. The air is, therefore, allowed to expand, thereby cooling itself; then it flows back over the pipes containing the oncoming air, thus cooling the whole body of air. This cool air is again compressed and expanded, growing colder with each expansion, until it is sufficiently near 350 degrees Fahrenheit so that the final expansion to atmospheric pressure liquefies it. Liquid air is 80 per cent nitrogen and 20 per cent oxygen, and commercial oxygen is 95 per cent pure. The balance is nitrogen and is not harmful for welding purposes.

Oxygen is sold in tanks containing 5, 25, 50, or 100 cubic feet, as desired, and the tanks themselves may be either bought or rented. They can be recharged when empty, and each tank is equipped with a reducing valve to regulate the pressure when using. A pressure gage must also be used, when using the oxygen, and leakage must be looked out for because of the high pressure.

The production of oxygen by the *electrolytic decomposition of water* is the method used most in Europe and gives two volumes of hydrogen to one of oxygen. The process consists in passing an electric current at a pressure of 2 or 3 volts through an electrolyte or solution of sodium or of potassium hydroxide. Direct current is used and oxygen rises from the water around the positive terminal plate and hydrogen from around the negative plate, each gas being conducted through separate pipes to compressors for storage. The tank, in which the electrolytic action takes place, is usually of cast iron and is divided into two sections by a partition running part way down. One terminal is placed in each section, and the temperature is maintained at about 165 degrees Fahrenheit because the action requires a lower voltage at this temperature than at any other. From 240 to 325 amperes are used and the gases are about 99 per cent pure. Purity is important because foreign elements may burn into the metal when welding.

The apparatus for making *oxygen from potassium chlorate* is comparatively simple and low priced and is especially suitable for use in out-of-the-way plants doing welding. The process is based on the fact that, when potassium chlorate is heated, it produces a somewhat large percentage of oxygen of 97 to 98 per cent purity. In order to prevent the chlorate from melting and flashing under heat, about 13 parts of manganese dioxide are mixed with each 100 parts of the potassium chlorate, and the gas is given three scrubbings before storing. The mixture is first packed tightly into a retort, heated slowly with a gas flame, and the oxygen is carried through three washer tanks, filled with a solution of sodium hydroxide, and then into a gasometer. From here it is compressed into steel cylinders at 300 pounds per square inch for service. The makers of this apparatus claim that there is but little oxygen lost through leakage because of the low pressures used; that but little oxygen is lost in recharging the retort for the same reason; and that the gas is thoroughly washed in the scrubbers because the bubbles are so large. One pound of chemicals costing about 8 cents will produce about 4½ cubic feet of oxygen at a total cost for everything of about 2¼ cents per cubic foot of gas.

Pintsch Gas. Pintsch gas was originally developed for lighting purposes and is used for lighting steam railway cars. It is an oil gas made from crude petroleum or similar oils and will safely stand a high degree of compression, it being used at various pressures for different purposes.. Works for the supply of the gas are now established in nearly all of the large cities in the United States, Canada, and Mexico and gas can be obtained in pressures up to 100 atmospheres (1500 pounds pressure per square inch). It can also be obtained in flasks at 12 atmospheres (180 pounds pressure), but it is used at about 25 pounds pressure for cutting and welding. On account of its high heating value and its stability, or resistance to pre-ignition, it is coming into use for high temperature work in conjunction with oxygen and bids fair to become a serious competitor of acetylene.

Water Gas. Water gas is a mixture of carbon monoxide and hydrogen and is formed by passing steam over or through incandescent coke, thus causing the steam to decompose into oxygen and hydrogen. The oxygen combines with carbon from the coke and forms carbon monoxide, with a little carbon dioxide, and a slight impurity in the form of hydrogen sulphide from the sulphur in the coke. The impurity can be removed with lime or iron oxide, as when making coal gas. Thirty-five pounds of coke are used for each 1000 cubic feet of gas, on an average, and the composition of the water gas is approximately as follows:

Hydrocarbons and vapors	14%
Carbonic oxides	31%
Hydrogen	31%
Oxygen	1%
Methane	20%
Nitrogen	3%
	100%

The apparatus used for generating water gas is comparatively simple and consists mainly of a generator and a superheater, with connections for taking off the gas and for the supply of air and steam. Water gas gives an extremely high temperature when burned and is used a great deal in Europe for heating metals preparatory to welding by hammering as well as for fusing, as in some other processes. Owing to its lack of odor when pure, it is dangerous if it escapes.

OXY-ACETYLENE WELDING

General Features. The oxy-acetylene welding process is the best known of the hot-flame systems and is based on the combustion of oxygen and acetylene at the tip of a torch as the source of heat. This process has apparently been developed to the highest possible degree and is probably the most efficient of the various hot-flame systems in general use, the flame having an approximate temperature of 3500 degrees centigrade. The practical value of this process was overestimated, when it was first introduced, and there are still many limitations to be overcome but improvements in torches, valves, generators, and storage tanks are being made and should result in improving its status. Owing to the low first cost, there are thousands of oxy-acetylene plants in use for welding and cutting, in spite of the high cost of operating, and reductions in the cost of the gases will eventually bring down the cost of operation to a more reasonable basis.

The principal elements of an oxy-acetylene installation are: the oxygen generating or storing apparatus; acetylene generating or storing apparatus; and the burner or torch with its connections. For large plants it will pay to install oxygen generating plants as well as the acetylene plants, but in other shops the oxygen is usually purchased in steel tanks and the acetylene is generated in small-sized outfits. For moderate sized shops a portable outfit can be used, consisting of an oxygen tank and a small acetylene generator, or an oxygen tank and an acetylene tank on an ordinary hand truck.

Acetylene Generator. The acetylene generator is a comparatively simple device, usually a single steel receptacle for holding the gas, with various attachments for controlling the action of the water on the carbide. There are two general systems of acetylene welding in use, the high pressure system and the low pressure system, both of which have their advocates. As a matter of fact, the so-called high pressure system, used in this country today, is a medium pressure system, the true high pressure system being used principally in France and not yet having been introduced commercially into this country.

Acetylene generators are made in five types, one of which only is used to any great extent for making acetylene for welding use. These are the "dip", the "drop" or "plunge", the "overflow", the "rescission", and the "spray" types, the drop type being the one most used.

Dip Type. The dip generator is so arranged that the calcium carbide is suspended in a sort of basket inside the gas holder and, as the gas is used, the basket is lowered until the carbide comes in contact with the water. More acetylene is then generated and this causes the pressure to raise the holder and basket, thus stopping generation until the gas is used.

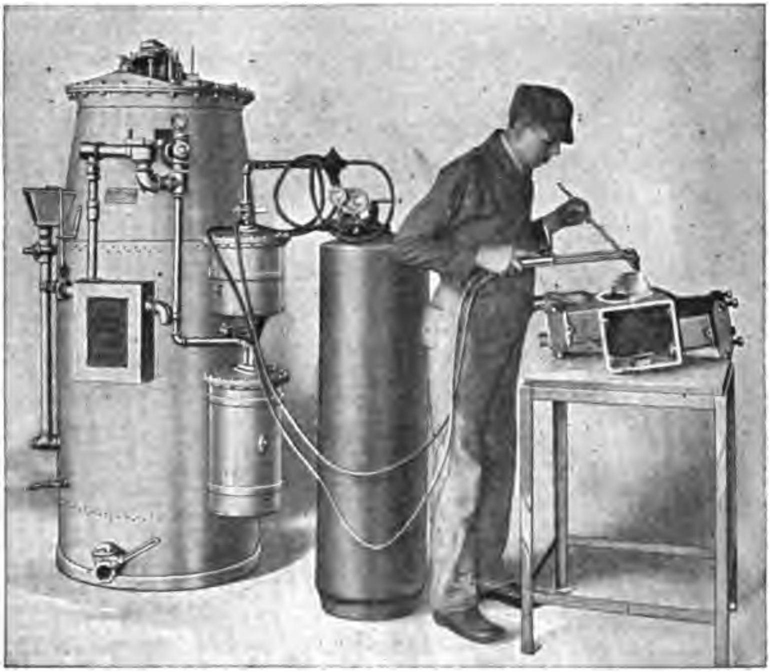


Fig. 112. 100-Pound Oxy-Acetylene Welding Outfit
Courtesy of Davis-Bournonville Company

Rescission Type. The rescission generator is similar in principle to the dip type, the only important difference being that the gas pressure forces the water away from the carbide basket instead of lifting it.

Overflow Type. The overflow generator has the carbide in a series of compartments, the water filling the first before overflowing into the second, then into the third, etc., until all of the carbide has been flooded.

Spray Type. The spray generator is one of the oldest types and has a pan of carbide located so that the water may drip into it from above. The supply of water is cut off when the gas pressure becomes too high and steam is frequently formed by the high temperature of the reaction. These machines are wasteful and dust from the carbide may clog the pipes and burner.

Drop Type. The drop or plunger type of generator is the most economical and satisfactory and has practically superseded all of the others. This type of generator is arranged so that the carbide falls a few lumps at a time into a large vessel of water, the feeding being done by suitable mechanism; the water absorbs the heat so rapidly that the gas is kept cool and the temperature of the entire outfit is much lower than with other types. The gas is washed by bubbling up through the water and the lime remains in the bottom and is frequently removed. This lime makes a good fertilizer. It has been claimed that this type of machine is inefficient because the water will take up gas at the rate of 1 cubic foot per cubic foot of water; but as the water becomes saturated with the lime, it causes the gas to pass out, so that only about three per cent of the gas is actually lost by this action. Theoretically, 1 pound of carbide requires ½ pound of water but, in practice, it takes about 1 gallon to the pound for the best results and should produce 4½ feet of gas.

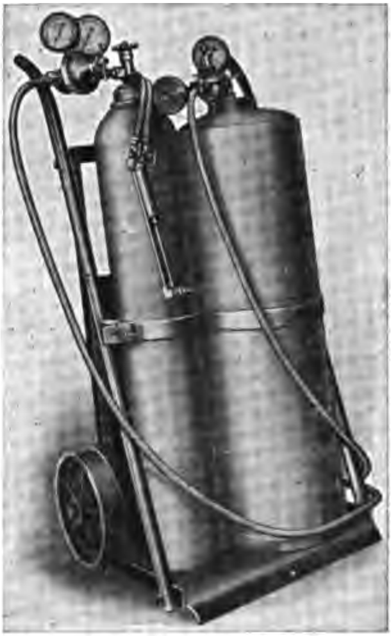


Fig. 113. Portable Welding or Cutting Oxy-Acetylene Unit
Courtesy of Davis-Bournonville Company

The best known acetylene generator on the market in America today is the Davis generator made by the Davis-Bournonville Company, New York, for use in connection with their welding apparatus, Fig. 112, made under the Bournonville patents. The carbide is fed into the machine through a hopper at the top in the form of lumps, because ground carbide will produce less gas, the carbide being dropped into the water as required. The feeding mechanism is on top and operates through variations in the gas pressure and through its effect on heavy weights and a moving gas bell. Attached to the tank are also a filter, flash-back chamber, drainage chamber, water filling tube, blow-off valve, and such other devices as are required for the safety and operation of the generator. The pressure of the gas may be varied and can be made to run up to 15 pounds if desired. These machines are made in sizes from 20 pounds carbide capacity up to 300 pounds capacity, a small-sized portable outfit being shown in Fig. 113.

Oxygen Generator. Oxygen generators are much more elaborate devices than acetylene generators and the methods of action of the large types have already been given on pp. 98 and 99. Most of the small plants, whose details may be easily understood, are for making oxygen from chlorate of potassium and consist of a generator, washer, gasometer, and compressor. The generator for the oxygen consists of a metal retort and a gas burner for heating it and the chlorate is mixed with a little manganese dioxide and heated in the retort. The vapor from this is usually carried through three scrubbers, consisting of barrels filled with a solution of sodium hydroxide, thence into a gasometer or tank to be stored until required. From the gasometer the oxygen is carried to a compressor, usually two-stage and there compressed for filling the cylinders at 300 pounds pressure per square inch. Oxygen of high purity can also be generated by wetting sodium peroxide; small outfits of this type have been put on the market under the name of "Oxone".

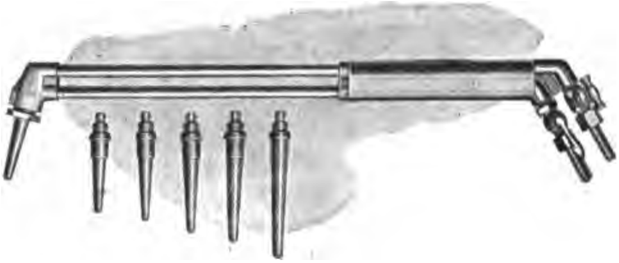


Fig. 114. Medium Welding Torch
Courtesy of Davis-Bournonville Company

Torch. The torch is the next item of importance in any good acetylene welding outfit and upon the development of this device alone depended the success of the oxy-acetylene process to a large extent. It has taken years to bring torches to their present state for the flame is very hot and the gases are highly explosive, yet they must be mixed and controlled accurately. The oxy-acetylene torch was probably invented by Fouche and was a high pressure device; so it was comparatively easy to get a good mixture but, later, it became necessary to develop a torch for low pressure work and it proved to be a difficult matter. It was done, however, and there are now three styles in use: the original high pressure torch, the medium or positive pressure torch, Fig. 114, and the low pressure torch. There is also a special torch for cutting with an extra oxygen feed in addition to the regular flame feed. The gases are regulated by cocks at the handle, and wire gauze is placed in the passages to prevent flashing back in case of too low pressure, somewhat on the principle of the miner's lamp. Torches are made in several sizes and have a series of removable tips to provide for various sized flames. Goggles for the eyes and gloves for the hands of the operator are necessary for his protection.

Automatic Cutting and Welding Machines. A recent development in connection with oxy-acetylene apparatus is the use of special cutting machines and welding machines which work automatically and displace hand welding and cutting. An attendant is necessary, of course, to see that the material is properly placed but the machine does such a high quality of work at such a uniform rate that it can turn out work of a simple nature more quickly and more cheaply than when done by hand. With this machine any irregular pattern may be cut quickly and accurately and it will cut steel 3 inches thick at the rate of 6 inches per minute. The welding machines are especially valuable for work on pipes, barrels, cylinders, cans, and other articles which are all alike, and some very efficient special machines have been built for such service. These automatic machines are not of any value for repair work, to be sure, and do not warrant the cost for any other than repetition or straight work. The torch is carried on an arm which is moved by the mechanism of the machine.

Process of Welding. *Adjusting the Flame.* The process of welding with the acetylene flame is similar to that of using the graphite electrode in electric-arc welding, as the flame is the source of heat and the filling material must be added as melted, but it has the disadvantage of being an open flame, which presents a certain element of danger. The first thing the operatorhas to do is to learn how to adjust his flame, and this is not easy because there is no rule for the exact proportion of oxygen and acetylene. It is approximately 1 part acetylene to 1.5 partsoxygen for most purposes. If the oxygen is as great as 2.5 against 1 of acetylene, an oxidizing flame will be produced which will probably cut the metal; if there is too much acetylene to be all consumed in the flame, itwill split up and allow carbon to enter the weld and carbonize it. The flame should be so adjusted that the two cones formed in the flame unite into a single small one. In operation, the tip of the white cone in the flame should just touch the metal and the hand should be held steady because, if the tip of the torch should touch the work, it will cause a flash back and necessitate relighting, if nothing worse. The torch should be given a sort of rotary motion around over the surface of the weld, with a slight forward and upward movement, in order to blend the metal and reduce the liability to overheat it.

Care for Expansion During Heating. All welding operations, whether with gas or electricity, should be undertaken only after a careful consideration of the effects of expansion and contraction on both the joint and the piece welded. This is especially important when welding castings, and even more so with the oxy-acetylene system than with the electric-arc system, because of the necessity for heating a comparatively large surface around the weld.

Preheating. Cast-iron pieces and articles of circular or closed shapes, such as wheels, should be preheated before welding and reheated afterwards to relieve any stresses which may be set up in them. Gas furnaces or oil burners make good preheaters as they are much cheaper than using the oxy-acetylene flame for heating preparatory to welding. Heating is necessary for practically all kinds of materials in order to prevent chilling of the flame and consequent loss of efficiency. It is also necessary to choose the proper sized tip to suit the work.

Conditions of Metal and Joint. It is important to have the surfaces clean before starting to weld and, if the parts have been cut with the flame, they must be chipped off in order to remove the oxidized material before being welded. Plates, to be welded should be beveled on the edges, unless they are less than ⅛ inch thick and filling material of similar composition used for the joint. If the plates are over ½ inch thick, it is advisable to bevel from both sides towards the center in order to balance the shrinkage strains and reduce the amount of filling required. The edges of the bevel should be from 30 to 45 degrees angle and the plates should be spaced slightly apart to insure filling clear through the joint. The opening should flare a little from the end where work begins to the opposite end in order to allow for the parts drawing together as the work progresses. Fluxes are an advantage in acetylene welding in order to absorb or reduce the oxide formed by the flame and to prevent burning out the carbon from high carbon steels, etc. They also protect copper and aluminum from oxidizing and reduce the liability of the zinc burning out of brass.

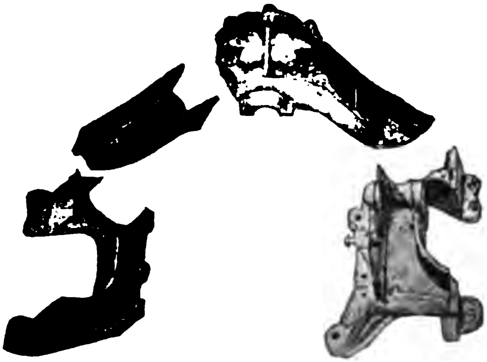


Fig. 115. Broken Aluminum Casting
Courtesy of Davis-Bournonville Company

Effects on Various Metals. *Aluminum* is very sensitive to oxygen; so an excess of acetylene in the flame is desirable when welding it. The metal does not run readily and must be puddled into place with a rod of iron. It should be hammered to toughen after welding, has a low melting point, and is difficult to weld. Figs. 115 and 116 show a successful piece of work with an aluminum casting.

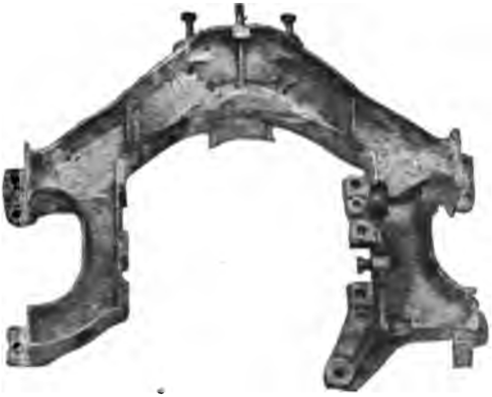


Fig. 116. Aluminum Casting Welded by Gas Torch
Courtesy of Davis-Bournonville Company

Brass can be welded readily with a moderately large flame, but the cone of the flame should be kept away from the metal. Borax is used as a flux for brass and the weld is usually not very strong because the material after being melted is merely cast brass.

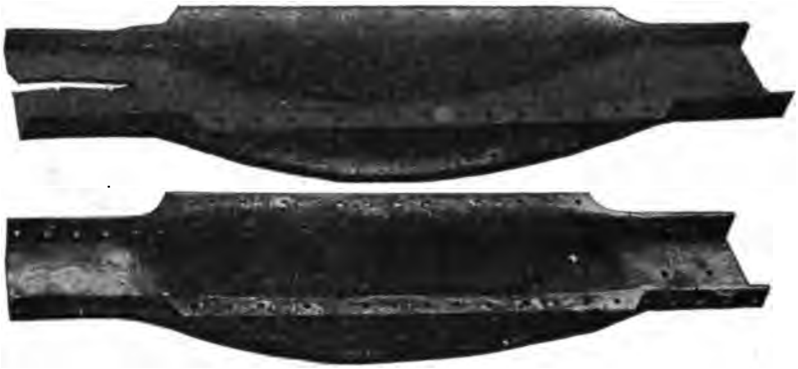


Fig. 117. Split Steel Bolster Welded by Gas Torch
Courtesy of Oxweld Acetylene Company

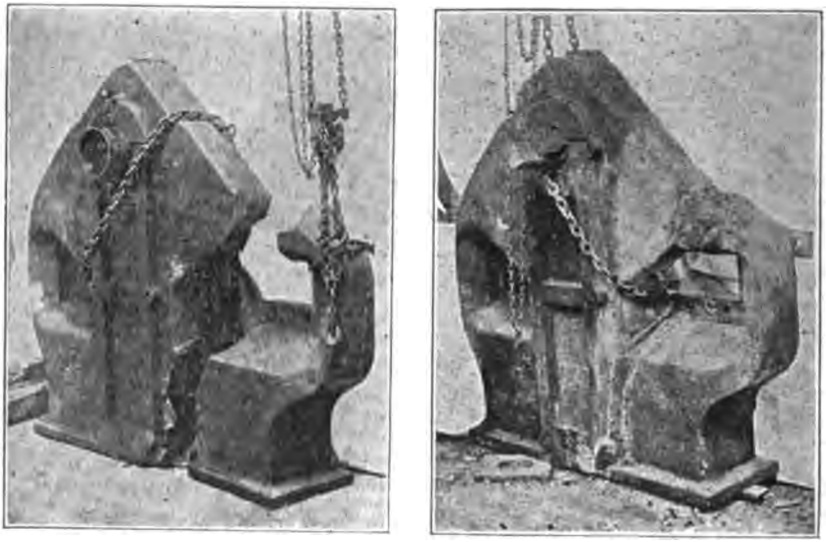


Fig. 118. Immense Shear Casting Broken and Welded by the Gas Torch
Courtesy of Davis-Bournonville Company

Copper should be welded with a low temperature flame and hammered afterwards to restore its toughness. Acetylene attacks copper, so care must be exercised to see that there is no excess in the flame as it may form acetylide of copper, which is a fulminate and can be exploded by striking with a hammer, or even by high friction.

Cast iron can be welded but is very liable to crack when cooling, so careful preheating is necessary before welding and slow cooling afterwards. High silicon cast-iron melt-bars, which are low in sulphur and phosphorus, are used, and borax forms this flux. Cast iron runs freely and a mold should be made around the spot to be welded to retain it, and the work must be done horizontally.

Wrought iron becomes cast iron when it cools—unless it is very low in silicon—and as it loses its structure it should be hammered to toughen it. It does not readily melt to a fluid but becomes a sort of thin paste and must be worked into place with the melt bar.

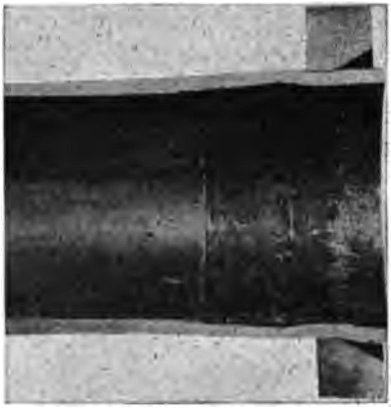


Fig. 119. Section of Boiler Flue Ready to Weld
Courtesy of "The American Machinist"

Fig. 120. Welded Boiler Flue
Courtesy of "The American Machinist"

Steel, with a small percentage of carbon, welds more easily than high carbon steel, and the carbon is liable to burn out or so change its structure near the weld as to destroy its essential properties. High carbon steels require careful heat treatment after welding to restore their original properties, and soft steel should be hammered to toughen it. Steel may be welded to iron or copper by proper manipulation but these are uncertain operations and are very seldom necessary.

Alloys of nearly all kinds may be welded with oxy-acetylene apparatus; the principal point to look out for is to be sure that the composition of the alloy is known before starting. If the flame is adjusted to suit the most sensitive metal and its action watched, there should be no serious trouble.

Applications of Oxy-Acetylene Welding. The applications of oxy-acetylene welding are almost as numerous as are the articles to be welded and apparatus of this type is in use in almost all lines of manufacture and repair. The low cost of the apparatus helped to give this system its present foothold and in many lines it has given entire satisfaction, especially on light work and where convenience is of greater importance than the cost of operation. Castings, forgings, sheets, and tubes of iron, steel, Fig. 118, copper, aluminum, etc., may be welded within the limitations just mentioned, and there is apparently no limit to the size of the piece which may be handled successfully, Fig. 118. Large articles cost more in proportion than small ones because of the greater amount of heat wasted in keeping them hot, but users of the system weld practically everything that comes along. Steel tanks are frequently welded instead of being riveted; car roof seams are welded instead of being soldered; steel furniture is welded in all the joints; cracked cast-iron cylinders are welded; boilers are patched and the flues welded in, Figs. 119 and 120; engine frames, crank cases, and automobile frames are repaired by welding. A good weld is stronger than a riveted joint and the cost is about the same.

Cost of Acetylene Welding. The cost of acetylene welding is very moderate on work of small or medium size but it becomes somewhat high on large work on account of the relative amount of heating to be done while welding. However, the advantages to be gained in quantity of production and even more so in cases of repairs because of the cost of new pieces, makes the system very valuable in many establishments. The cost of welding sheet steel per foot of length of seam is given in Table XIV and it will be interesting to compare this with the cost of doing the same work with the electric-arc system. This table was furnished by the Davis-Bournonville Company.

Repair Work. It is difficult to get accurate figures on the cost of doing miscellaneous repair work because the average repair man does not like to tell, but the following are the charges made in one automobile repair shop and will give an idea of what such work costs because the profits charged are usually 100 per cent of the cost.

TABLE XIV

Approximate Cost of Oxy-Acetylene Welding

Tip Number	Thickness of Metal in Inches	Consumption of Acetylene in Cu. Ft. per Hour	Consumption of Oxygen in Cu. Ft. Per Hour	Proper Pressure in Pounds for Oxygen	Lineal Feet Welded Per Hour	Cost of Labor Per Hour	Total Cost Per Hour	Cost per Lineal Foot
1	$\frac{1}{32}$ to $\frac{1}{16}$	2.8	3.6	8 to 10	50	$0.30	$0.436	$0.0087
2	$\frac{1}{16}$ to $\frac{3}{32}$	4.5	5.7	10 to 12	30	.30	.516	.0172
3	$\frac{3}{32}$ to $\frac{1}{8}$	7.5	9.7	12 to 14	25	.30	.666	.0266
4	$\frac{1}{8}$ to $\frac{1}{4}$	11.7	15.	14 to 18	16	.30	.867	.054
5	$\frac{1}{4}$ to $\frac{5}{16}$	18.	23.	18 to 22	10	.30	1.17	.117
6	$\frac{5}{16}$ to $\frac{7}{16}$	25.	32.	20 to 25	7	.30	1.51	.216
7	$\frac{7}{16}$ to $\frac{1}{2}$	32.5	41.5	22 to 27	5	.30	1.87	.374

NOTE: The acetylene is used at a pressure of about 3 lbs. per sq. in. The cost of oxygen is estimated at 3 cents, and of acetylene at 1 cent per cubic foot. Labor is estimated at 30 cents per hour.

Welding axles, from	$2.00	to	$5.00
Cracked cylinder water jackets	8.00	to	12.00
Broken cylinder lug welded on	2.00	to	4.00
Cylinders cracked inside	12.00	to	20.00
Broken crank case, aluminum	5.00	to	20.00
Main side frames broken, each	15.00	to	25.00

Defects, known as "cold shuts", frequently develop in steel forgings and the average cost of welding these is from 50 cents to $2.00 each. Engine connecting rods have been welded at $3.00 to $12.00 each, depending upon the size. Stern posts of vessels frequently break during storms and these can be welded for $35.00 on small ones up to several hundred dollars for large ones. Blow holes in iron castings cost 25 to 75 cents to fill in.

The following figures on various repair jobs have been compiled by the Oxweld Acetylene Company, Chicago, and cover a wide variety of work:

Welding stern post of lake steamer "Mullen"	$32.00
General repairs on Cahall water tube boiler	29.49
Small cast-iron gas engine frame, sand spot in one side	.40
Broken locomotive side rod, steel forging	5.22
Short crack in locomotive side sheet, 4 inches long	2.50
Cracked locomotive mud ring, nine hours	22.00
Small patch in side sheet of locomotive fire box	10.01
Medium sized patch in side sheet of fire box	17.38
Three short cracks in fire box sheets, 11 inches total	3.46
Small repairs to steel railway motor case	8.82
Welding lugs on small shaper arm, steel casting	4.50
12-inch crack in end of pressed steel car bolster	6.16
Crack in cast-steel truck side frame, "Andrews" truck	.85
Welding small lug to cast-iron cylinder head	5.89
Patch on side of aluminum crank case for automobile engine	1.50
Cutting risers from large steel castings, per sq. in.	.014

In conclusion, the student is urged to familiarize himself with the rules laid down by the National Board of Fire Underwriters concerning the installation, care, and operation of oxy-acetylene and other types of hot-flame welding apparatus. The complete rules are too lengthy for reproduction here, but a copy can be obtained from the headquarters of the Board in Chicago and will be interesting reading.

OXY-HYDROGEN WELDING

The use of oxygen and hydrogen as the gases for welding and cutting is older than the oxy-acetylene process and dates back to before the production of oxygen by either electrolysis or liquefaction of air. Oxygen was probably generated in those days from potassium chlorate and manganese dioxide, or perhaps from potassium and sodium peroxides and water, and the hydrogen from hydrochloric acid and zinc. The oxy-hydrogen process was developed by Newman who used detonating gas (pure oxygen and hydrogen mixed) at a pressure of about 3 atmospheres. This gas is still used to some extent in welding platinum, lead, and precious metals but it is rapidly being superseded by apparatus designed to use the oxygen and hydrogen from separate cylinders.

Equipment. The apparatus required for oxy-hydrogen welding is similar to that in use for oxy-acetylene welding and consists primarily of the two steel cylinders for the oxygen and hydrogen (at pressures of 1500 to 2000 pounds per square inch); a mixer and insulator of the gases, together with a regulator; high pressure reducing valves for each of the gases; armored hose; and the special blowpipe, or torch. When the blowpipe is used, there are two tubes leading to it, one for the oxygen and the other for the hydrogen, and the blowpipe is made with an inner and an outer tube. The oxygen is carried through the inner tube and the hydrogen is carried through the outer tube and lighted first. After the oxygen is turned on, the flame is adjusted to suit the work in hand and the mixing is done in the tip of the blowpipe just before the gases enter the flame. Hydrogen and air can be used with the same sort of blowpipe for light work requiring but moderate heat, such as lead burning, but the process is much slower and more expensive than with the oxy-hydrogen flame.

For commercial welding another type of torch is used and the gases are combined in the mixer and carried to the burner through a single tube. This torch has an enlargement, where the gases enter, which reduces their velocity; from this chamber the gases pass through the smooth tubular body to the nozzle. The latter diminishes in size toward the tip and causes the gas to increase in speed up to the proper velocity.

Handling Oxy-Hydrogen Torch. The oxy-hydrogen flame is pale blue, almost colorless in fact, and has a temperature of about 2000 degrees centigrade. When lighting the torch, the hydrogen should be turned on about two-thirds and ignited; the oxygen should then be turned on enough to give a pale blue conical flame, and then the hydrogen should be turned on full. This will take but a few seconds, and a flame, which will not melt the metal too rapidly, is better than one of such intensity as to burn the work. The end of the cone of oxygen in the flame should never touch the work or that will burn it also. When through welding, the oxygen should be turned off first. Theoretically, two parts of hydrogen should be used for each part of oxygen but experience shows that it is desirable to use about three parts of hydrogen to one of oxygen. Some operators advocate using even more hydrogen, but this is not necessary when the gases are properly mixed before entering the flame.

Process of Oxy-Hydrogen Welding. The process of welding with oxy-hydrogen is similar to other hot-flame processes and the joints must be beveled in the same way to make them accessible for filling. The work should be heated first, in order to prevent chilling of the filling material, and the melt bar fused in to make the joint. In Germany this gas is used to heat plates and then they are welded by hammering, as in blacksmith work, this operation being used to a large extent in making large steel pipes. Iron, steel, copper, lead, zinc, and the other industrial metals can be welded by this process; the cost is similar to that for work done by the oxy-acetylene process, although somewhat higher for most operations. Each metal requires its own special method of treatment and the operator will soon learn the best ways of handling each job, but this process requires a skilled workman and the success or failure of the weld will depend largely on the man who does it.

Time Required for Weld. The time required for welding seams in steel plates will vary from two minutes per foot on $\frac{1}{32}$-inch sheets up to five minutes on $\frac{1}{4}$-inch plates. It is claimed that the oxy-hydrogen flame does not affect the ductility of the metal like the oxy-acetylene flame and, if this is true, it should be good for boiler repairs and other work in which this quality is desirable.

OXY-PINTSCH GAS WELDING

The use of pintsch gas and oxygen for hot-flame welding is the latest addition to the list of possible systems for general use, and was developed by the Safety Car Heating and Lighting Company, New York, primarily for use by steam railroads. It is as general in its applications, however, as any of the other systems and the fact that every railroad has pintsch gas on its cars and supply stations at frequent intervals should result in a wide application in shops which have no electric-arc welding apparatus. The principal feature of this process seems to be in the use of a special torch, as with the other gas systems, and the apparatus is similar.

Equipment. The apparatus consists of the two steel cylinders for the gases, valves for regulating the pressure, tubes for the gas, and the special torch. The pintsch gas is furnished at a pressure of 100 atmospheres (about 1500 pounds) and the oxygen at 150 pounds. The gas can also be obtained at 180 pounds pressure. The high pressure gas is reduced in two steps when used, the first being from 100 atmospheres to 14 atmospheres and then down to the 25 pounds required at the torch. The torches for this process are made to take the two tubes feeding the two gases and mixing them in a chamber at the back end, and a valve is provided in each inlet. The tip of the torch contains a preheater which operates by internal combustion and produces a high temperature, non-oxidizing flame. This feature of the torch is valuable and adds to the temperature of the flame.

The process of welding with the oxy-pintsch flame is the same as with the oxy-acetylene flame, but the manufacturers claim considerable saving in cost of operation. They give 3.4 cents as the cost of cutting one foot of an 18-inch channel $\frac{15}{32}$ inch thick, and the total cost of the work done on the channel was 86.2 cents against the old cost of $4.66 by drilling and chipping. No figures are available at this time for welding operations, but all sorts of articles can be successfully welded and cut by this process. The preparation of the joints should be the same as for other gases and the metal should be handled in the same way.

BLAU-GAS WELDING

General Advantages. The advantages claimed for the blau-gas process are safeness, cheapness, compressibility of the gas to a liquid, high B. T. U. (1800 per cubic feet), and convenience. On the other hand, the oxy-blau gas flame is not so hot as the oxy-acetylene and must be larger to do the same work. This is sometimes a disadvantage. This system is well established in Europe but has been adopted in this country only a few years and has not proved a very serious competitor of the other systems. Blau gas is distilled from fuel oil at only 600 degrees centigrade; so the hydrocarbon gases are not broken up and very little tar or methane is formed. During liquefaction for the market, the distillate is first subjected to two compressions which liquefy the low pressure gases and these are drawn off with the cooling water. The heavier gases are then compressed in two more stages and absorb most of the permanent gases when they liquefy.

Equipment Cylinders. The apparatus used for blau-gas welding consists of the regulation gas cylinders containing blau gas at 100 atmospheres pressure, cylinders with compressed oxygen, a gas expansion cylinder, pressure indicating and reducing gages, tubing, and high pressure torches. Owing to the blau gas being composed of gases of different critical pressures it must not be drawn from the top of the cylinders direct; so a tube extends through the liquid gas to the bottom of the cylinders and the heavier liquid is drawn off first. This expands in the expansion cylinder and blowpipe before entering the flame, and the lighter gases are drawn off last. The customary glasses should be provided for the workmen's eyes.

Torch. The welding torch has several sizes of tips and the cutting torch is so arranged that there is a preheating flame around the oxygen inlet. Liquid blau gas is first let into the expansion chamber at about 50 pounds pressure and then into the torch at from 10 to 20 pounds, depending upon the work to be done. The oxygen is led directly to the torch at pressures of 15 to 30 pounds for the various operations. Cutting requires higher pressures than welding.

Process of Blau-Gas Welding. The process of welding with the oxy-blau gas apparatus is similar to the other hot-flame systems excepting that its heating value is less and a larger spread of flame is required to give the required amount of heat units and temperature for the work. The explosive range of blau gas is 4 per cent and ranges from 4 parts gas to 96 parts air up to 8 parts gas and 92 parts air. Up to the present time its principal application has been to cutting, but it has been used for welding practically everything and a large amount of steel piping and tank work has been done with it. It is comparatively safe to use because it is chemically inert, nonpoisonous, and leaves no deposit in the pipes.

Water-Gas Welding. Water-gas welding is done by mixing oxygen with the gas and using it in a manner similar to the other gases. The gas is drawn from the mains and carried to the torch and there mixed with the oxygen for use. Its application is not very general because of its low heating value, but it is cheap when it can be obtained at all. It can also be obtained compressed into cylinders like the other gases but there is very little to recommend it for general use in view of the gradual reductions in cost of acetylene.

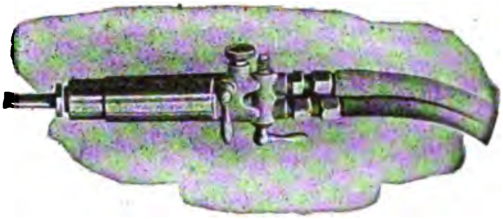


Fig. 121. Davis-Bournonville Cutting Blowpipe

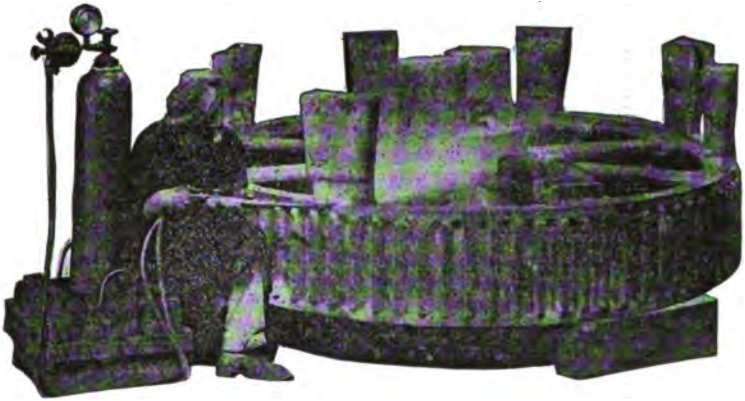


Fig. 122. Cutting Risers from Large Gear
Courtesy of Oxweld Acetylene Company

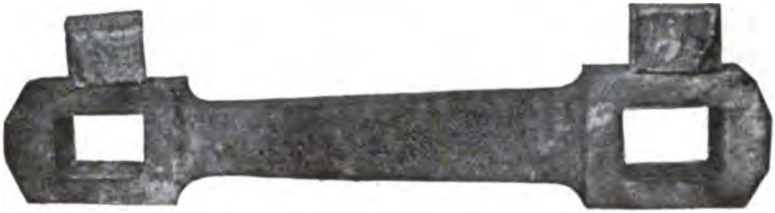


Fig. 123. Crosshead Slots Cut Out of Drop Forging
Courtesy of Oxweld Acetylene Company

CUTTING WITH GASES

All of the gases described for welding are also used for cutting and offer some advantages over other methods of cutting for various purposes. The work is done by heating the metal to about 1500 degrees Fahrenheit with a flame composed of oxygen and the gas used, and then directing a blast of oxygen against the heated surface. At that temperature the iron or steel has a great affinity for oxygen; so the metal is oxidized or burned up so rapidly that a clean cut is made in the piece. The metal is entirely destroyed, of course, but the work is done so quickly and the slot cut is so narrow that it is considered no disadvantage. The metal passes off in the form of an oxide. Pieces of almost any commercial thickness may be cut and blast-furnace tap holes have been cut out to depths of 4 feet of metal.

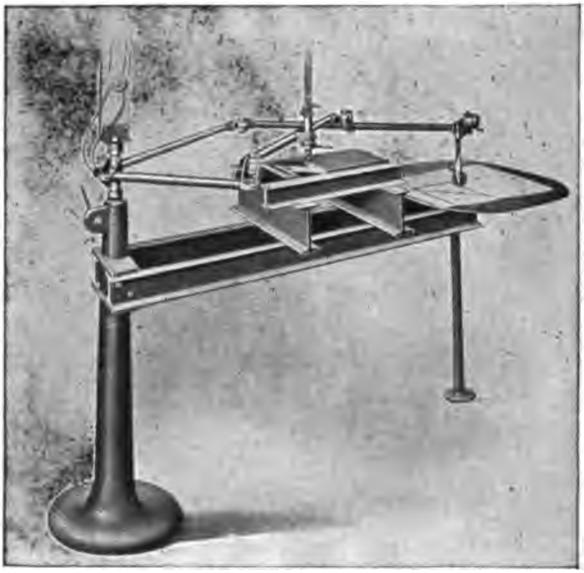


Fig. 124. Oxygraph for Cutting Steel According to Pattern with Oxy-Acetylene Flame
Courtesy of Davis-Bournonville Company

Equipment for Cutting. The apparatus required for cutting consists merely of a torch, Fig. 121, tubes for the gas and oxygen, and a source of supply of gases. The gases are generally supplied in tubes as for welding, and portable outfits are most convenient for all-around use. The torches used for cutting differ from those used for welding in that an extra stream of oxygen must be carried to the tip end, and this is generally done by an extra tube along one side of the torch. In some forms the oxygen is then carried through the preheating flame, but the most efficient types are those in which the oxygen is brought into contact with the metal just back of the main flame and so directed as to cause the oxygen to strike the hot spot. The composition or hardness of the metal have no apparent effect on the speed of cutting and chrome nickel steel armor plates 9 inches thick can be cut at the rate of 2¼ minutes per foot of cut, with oxy-hydrogen flames. Figs. 122 and 123 show heavy pieces which have been cut with hot-flame apparatus. Numerous cutting machines have been devised for automatic work, among which are those for holes, rails, cams, irregular curves, and straight lines, Fig. 124, and they are much more rapid and efficient than

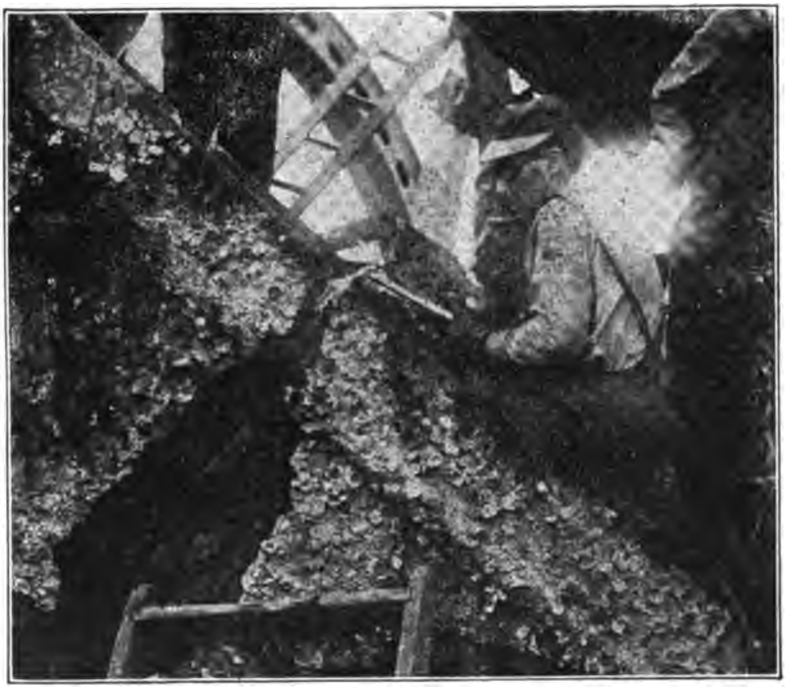


Fig. 125. Cutting up the *Maine* with Gas Blowpipe
Courtesy of Oxweld Acetylene Company

hand cutting because of their uniform feed and speed. For work on which they can be used they are a good investment.

Applications of Hot-Flame Cutting. The applications of hot-flame cutting are so numerous that only a few of them need be described in order to give a good general idea of its possibilities. The accompanying examples were done with oxy-acetylene, oxy-hydrogen, and other gases and the work is very similar with all of them. The principal characteristic of the work done is the smoothness of the cut, and the cost compares very favorably with that of cutting with the electric arc. It is cheaper than the arc on moderate and small work but more expensive on large work. The low first cost of the outfit makes it appeal to small shops and scrap dealers, although it is very valuable for cutting up junk and all sorts of wreckage. The battleship *Maine* was dismantled with an Oxweld acetylene outfit, Fig. 125, and the ruins of the Quebec bridge were also cut away with this apparatus, Fig. 126. Manholes in tanks and boilers, portholes in steel vessels, ruins of burned or wrecked build-

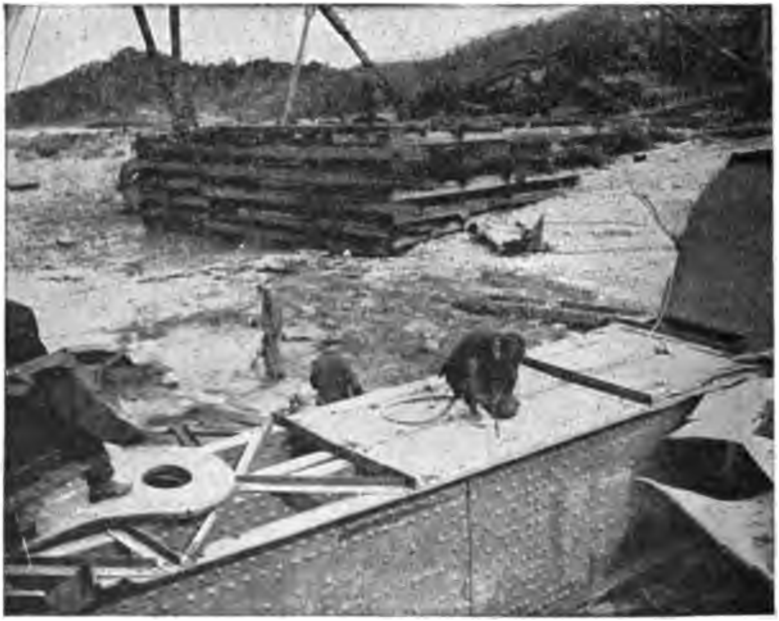


Fig. 126. Cutting up Ruins of Quebec Bridge with Acetylene Blowpipe
Courtesy of Oxweld Acetylene Company

TABLE XV

Cost of Cutting per Foot of Cutting Length

Thickness of iron in inches	⅛ in.	¼ in.	5/16 in.	⅜ in.	½ in.	⅝ in.	¾ in.	1 in.	1¼ in.	1½ in.	2 in.
Cunsumption of oxygen in cubic feet per foot of cutting length	0.45	0.50	0.60	0.90	1.30	1.90	2.50	3.10	4.00	5.60	7.60
Consumption of acetylene in cubic feet per foot of cutting length	0.12	0.13	0.13	0.18	0.19	0.21	0.25	0.30	0.36	0.41	0.47
Length of time in minutes per foot of cutting length	1	1	1	1¼	1¼	1⅓	1⅓	1⅓	1½	1½	1¾
Total cost in cents per foot of cutting length	1.25	1.35	1.5	2.1	2.7	3.7	4.6	5.7	7	9.5	12.75
Thickness of iron in inches	2½ in.	3 in.	4 in.	5 in.	6 in.	7 in.	8 in.	9 in.	10 in.	11 in.	12 in.
Consumption of oxygen in cubic feet per foot of cutting length	8.25	11.80	15.30	20.60	26.00	32.00	37.00	44.00	51.00	59.00	68.00
Consumption of acetylene in cubic feet per foot of cutting length	0.60	0.90	1.20	1.40	1.65	1.90	2.10	2.35	2.70	3.10	3.25
Length of time in minutes per foot of cutting length	2	2½	3	3	3½	4	4	5	5	5½	6
Total cost in cents per foot of cutting length	14.5	20	25	34	42	52	59	71	82	95	108

This table is based on a price of $1.50 for 100 cubic feet of oxygen, of 3½ cents per lb. for the calcium carbide and on an expense for wages of 35 cents per hour. The figures relating to the consumption of material are but approximate and are supposed to be for straight cutting. The necessary proficiency and experience can be acquired in a few days.

ings, and, in fact, almost anything of metal may be cut by this process rapidly and conveniently. It is not necessary to have the article in any particular position as the work may be done wherever the operator can carry his torch. Work has been done on the top of high towers and stacks and down in deep holes and in steam vessels, inside locomotives, and on the lower side of bridges.

The cost of cutting steel pieces, per foot of length, using the oxy-acetylene flame is given in Table XV by Messer and Company, Philadelphia, and is approximately correct for other systems.

Cost of Hot-Flame Cutting. The cost of cutting will depend upon the cost of the gases, cost of labor, the nature of the work, and the facilities for handling it, but a few typical jobs will give a good idea of the possibilities. The accompanying connecting rod forging for a stationary engine is 6 inches thick and the crosshead slots are each 9½ inches by 7 inches in size and were cut out in 15 minutes each. The total cost of the operations was $6.00, including labor and gas; whereas the usual method of drilling and chipping would have taken 8 hours for each slot and have cost more. In steel and iron foundries this system is used for cutting off risers and gates from the castings and, in boiler shops, for cutting plates of considerable thickness, cutting off rivet heads, cutting holes, etc. The 4×6 foot plate, $\frac{9}{16}$ inch thick, shown in one of the illustrations is a cross brace plate for a locomotive frame and was cut as shown in one hour. The total amount of cutting was 264 lineal inches, which is at the rate of 3¾ minutes per running foot. Where articles are to be welded after cutting, it is necessary to remove the oxidized surface from the cut before welding. This can be done with a pneumatic chisel.

THERMIT WELDING

Welding by the thermit process is really "cast welding", because it is accomplished by pouring "thermit steel" around the parts to be joined. The main difference between this and other methods of cast welding lies in the method of producing the molten metal. The name for the process is derived from the Greek word *therme*, meaning "heat", and signifies that it is a heat process of welding or that the metal is produced by heat. The name was originally adopted as a sort of trade-mark but has come to be accepted as the name of the process.

Chemical Reactions in Thermit Welding. The thermit welding process is based upon a long series of experiments carried on for a number of years by various physicists and metallurgists to find some method of reducing metals readily from their oxides and ores. It is the direct result of the work done by Dr. Goldschmidt, of Essen, Germany, in what is now the new field of aluminothermics, and is based on his discovery that if finely divided metallic oxides are mixed in certain proportions with finely divided aluminum they will, if ignited, fuse and produce a temperature of 5400 degrees Fahrenheit in less than 30 seconds without the use of heat or power from the outside. The high affinity of aluminum for oxygen will cause it to draw the oxygen from the metallic oxide, combine with it to form aluminum oxide, raise the temperature of the mass by the violent reaction, and set the metal free. The greater weight of the metal will cause it to flow down through the mass in the container and the aluminum slag will rise to the top.

For ordinary commercial welding purposes in machine shops and foundries, iron oxide is used and the reaction takes place according to the equation.

$$Fe_2O_3+2Al=2Fe+Al_2O_3$$

The liquid steel produced by this process represents one third of the original material by volume and one half of the original mixture by weight, the balance being lost as slag. This method of cast welding was developed about the year 1900 and the peculiar reaction used has also been applied to the production of numerous kinds of alloys and metals free from carbon. Further reference will be made to this.

Analysis of the Composition of Thermit Steel. According to data furnished by the makers of thermit welding apparatus the average analysis of thermit steel is as follows:

Carbon	0.05 to 0.10
Manganese	0.08 to 0.10
Silicon	0.09 to 0.20
Sulphur	0.03 to 0.04
Phosphorus	0.04 to 0.05
Aluminum	0.07 to 0.18
	0.36 to 0.67

The balance of the mixture is iron.

Method of Starting the Reaction. During the experiments leading to the development of thermit welding, the mixture of metallic oxide and aluminum was heated from the outside to start the reaction, but finely divided aluminum will not melt at the temperature of cast iron and it was necessary to heat the mass so high that when action started it resulted in an explosion. So Dr. Goldschmidt used a storm match to ignite a fuse of barium peroxide, (BaO) which in turn ignited the mixture and started the reaction.

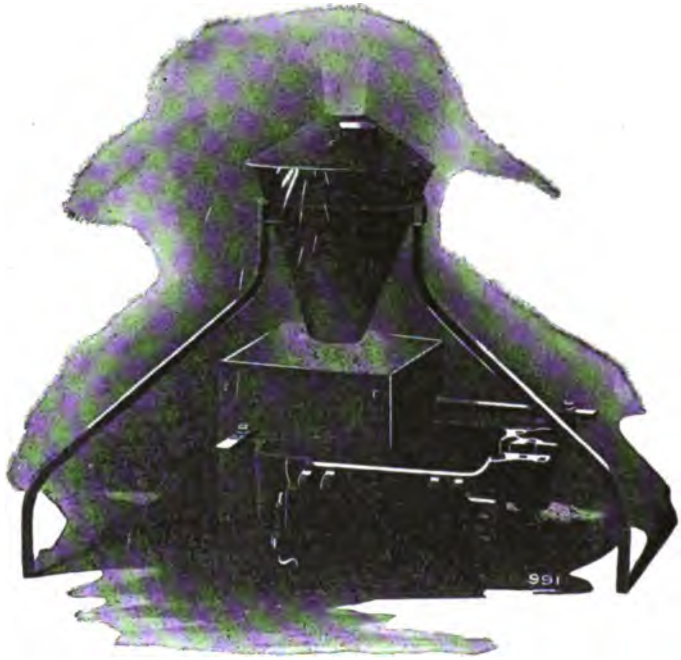


Fig. 127. Thermit Crucible Pouring Charge into Mold
Courtesy of Goldschmidt Thermit Company

Equipment for the Process. The apparatus required for thermit welding consists of a crucible, tripod, preheater, yellow wax, and a spade, with which there must also be used perishable materials consisting of thermit, manganese, molding material, and ignition powder. The shell of the crucible is of sheet iron and it is lined with magnesia in order to stand the high temperature and has a magnesia stone thimble at the bottom through which the metal flows. The process of preparing the lining is rather elaborate and must be carefully done or the life of the crucible will be greatly reduced. The tripod is used to support the crucible above the work, and the preheater is a combination compressed air and gasoline outfit used to heat the article to be welded in order that it may not chill the filling material. The wax is for forming the space to be filled when welding and about which a mold is made. It is melted out of the mold before welding.

Preparing the Mold. The process of preparing the crucible and the mold are the principal features of the entire operation of thermit welding, as the mere act of casting the weld is comparatively simple. The crucible, which is shown in Fig. 127, suspended above the mold, is a sheet-iron shell with a hole below for the metal to pass through. It is to be lined with magnesia, carefully packed while hot enough to be plastic, and with a magnesia stone thimble at the bottom to form a bushed hole and protect the crucible. The magnesia lining should be put into place slowly and carefully and tamped tightly into place, for its value depends largely upon how hard it is packed. The lining is formed around a matrix to shape the hopper-like center and must be baked at a dull red heat for six hours before it is ready to use. A crucible will withstand about 20 reactions if well made, and must then be relined. The thimble must be placed in the bottom of the crucible so as to be removable.

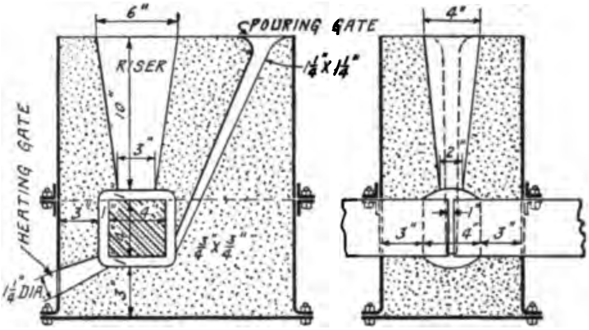


Fig. 128. Section of Typical Thermit Mold Showing Riser, Pouring Gate, and Heating Gate
Courtesy of Goldschmidt Thermit Company

Construction of Mold. The construction of the mold is really the most important part of the operation, because upon this depends the amount and application of the filling material. The container or flask is usually made of steel plates placed so as to form a box around the part to be welded, and then filled with the clay, etc., of the mold, the plates being fastened with bolts, tie-rods, clips, or clamps of whatever sort may be available, Fig. 128. The first step in the formation of the mold is to build a collar of the yellow beeswax around the place to be welded, making this of the size and shape desired for the weld. After the collar is formed, the flask is placed around it and filled with a mixture of ground fire brick, fire clay, and fire sand in equal parts. There must be three channels in every mold, a pouring gate, a riser, and a heating gate. The pouring gate should run from the top of the mold down to the bottom of the wax collar to insure the metal filling the mold and to allow the good steel to reach the weld instead of being crowded out by the slag. The riser should be immediately above the wax collar, if possible, so that the slag and surplus metal can rise freely from the metal of the weld, and the heating gate should run from one side of the mold into the bottom of the collar in order that the wax can

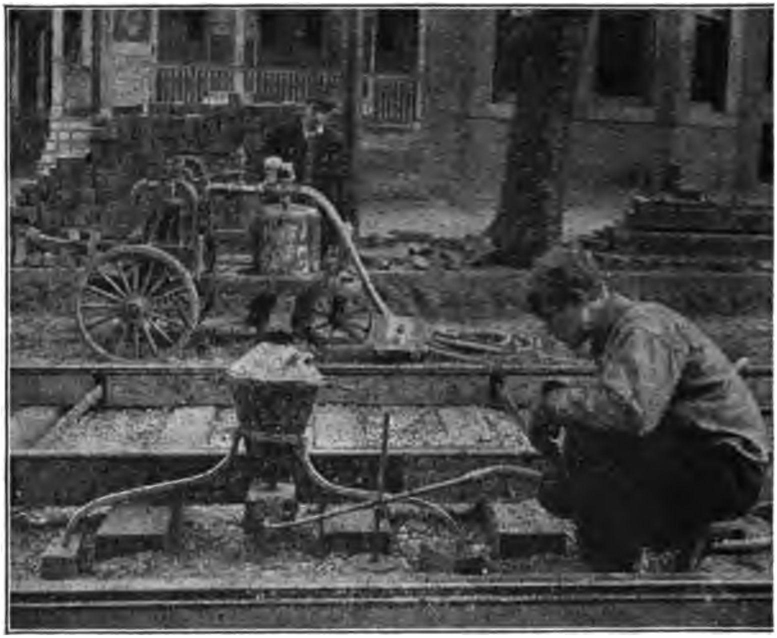


Fig. 129. Preheating Steel Rail Prior to Forming Weld
Courtesy of Goldschmidt Thermit Company

all run out of the mold when melted by the preheating torch. As soon as the mold is completed, the torch is applied and the wax melted out, Fig. 129. The flame is allowed to play into the mold until it is entirely dry and then the heating gate must be plugged with clay to stop it up entirely. Fig. 130 shows a typical thermit weld, with pouring gate and riser still attached.

Thermit Required for a Given Weld. The amount of thermit required to make a given weld will be twice the amount necessary to fill the space formed by the wax collar, because one-half of the weight of the original powder will rise in the form of aluminum slag, as already stated. On the other hand, the cubical area of riser and gate must be twice as great as the collar because the volume of the slag will be two-thirds of the total volume of the casting. It has been determined by experience that the weight of thermit necessary for a given job will be 32 times the weight of the wax required to form the collar for the mold; so the wax should be weighed after melting out of the mold in order to know how much thermit is required for the job. The size and shape of the mold and riser and gate will vary somewhat for different jobs and the relation between weight of wax and mixture will vary accordingly, but the ratio of 32 to 1 is a good average. It is necessary to preheat the article at the joint until it is red-hot before starting to pour the metal, and this is done with the gasoline torch through the heating gate at the bottom of the mold before plugging it.

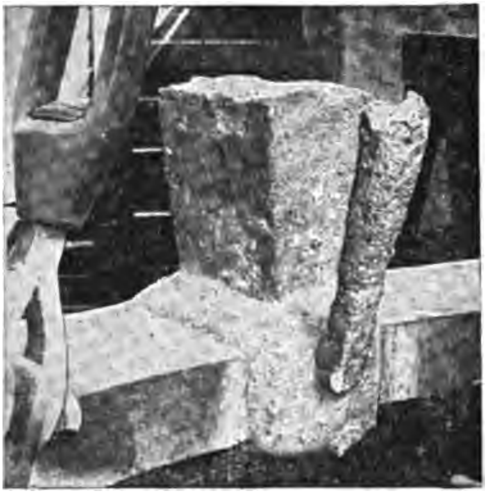


Fig. 130. Typical Thermit Weld Showing Riser and Pouring Gate Casting Still Attached
Courtesy of Goldschmidt Thermit Company

Addition of Other Materials. When more than 10 pounds of thermit are required for the weld, it is necessary to moderate the heat of the reaction slightly, and this is done by adding small pieces of clean steel to the powder. These may be punchings, rivets, or any other soft-steel pieces but must be free from grease to keep carbon out of the mixture, and from 10 to 15 per cent of the weight of the thermit may be added in this way. About 2 per cent of pure metallic manganese should also be added in order to increase the strength of the weld. If the manganese is not obtainable, 3 per cent of ferromanganese may be added instead, although it increases the violence of the reaction and hardens the metal.

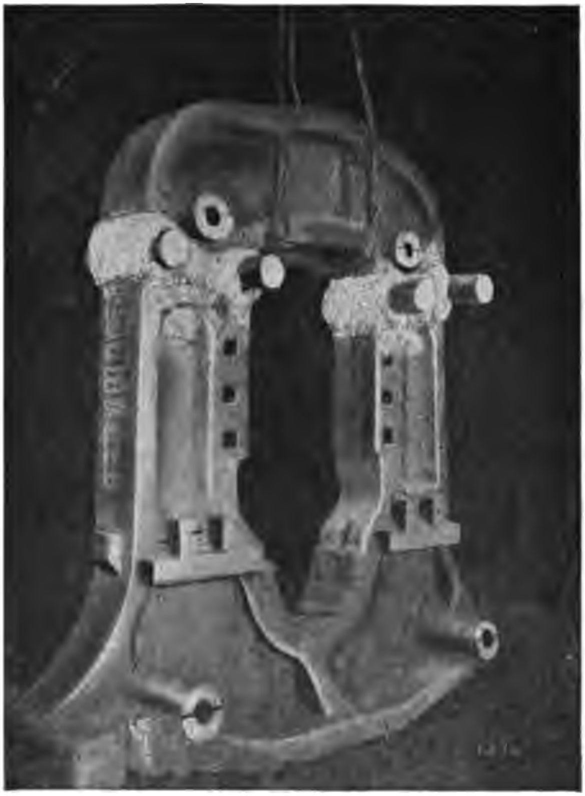


Fig. 131. Rolling Mill Housing Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

Strength of the Weld. The average tensile strength of the welds made with thermit are 30 tons per square inch of cross section and, if the joint is properly made, it will be hard to see where it is.

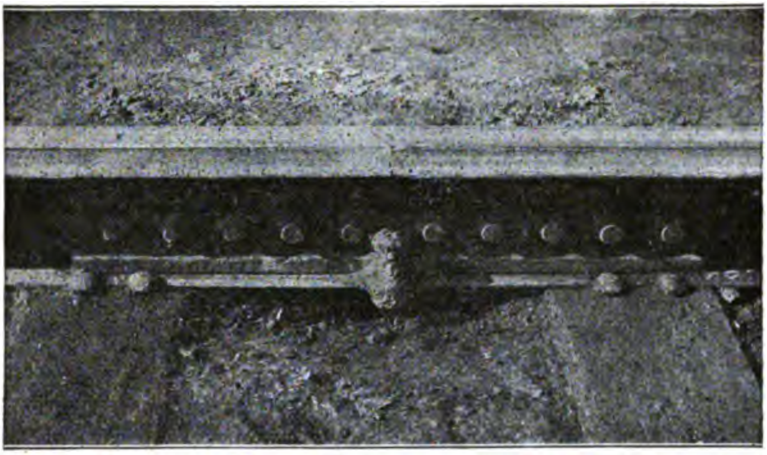


Fig. 132. Rails Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

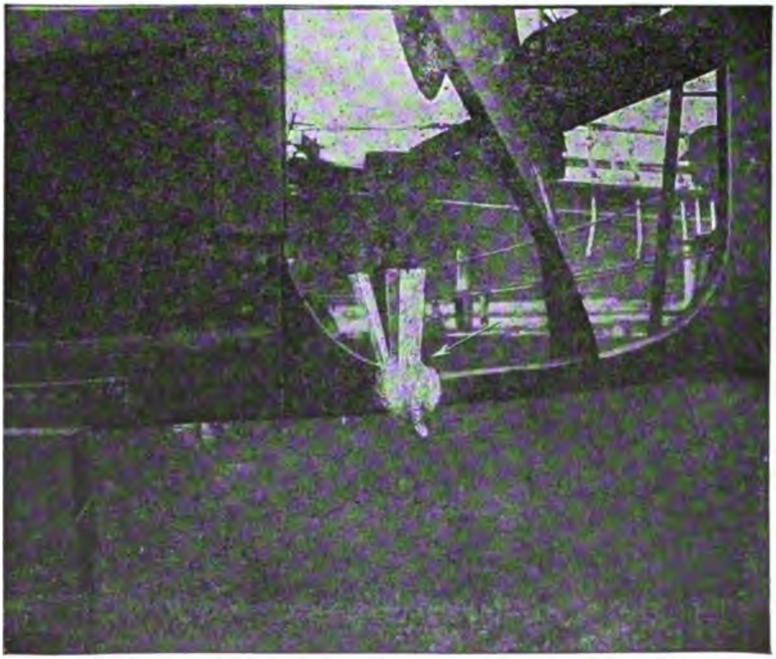


Fig. 133. Broken Stern Post of Boat Welded by Thermit Process
Courtesy of Goldschmidt Thermit Company

If a reinforcement can be left around the weld, it will give a higher strength than the original material, but where it is machined off the strength will average 80 per cent of that of the piece welded unless it be of unusually high tensile strength. When preparing the joint for welding, it is best to leave an opening for the metal to flow into, and this should be at least ¾ inch wide, preferably more.

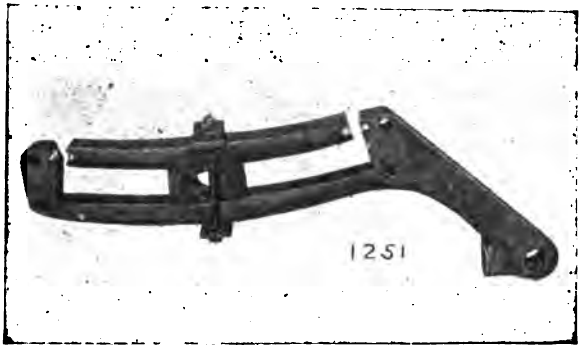


Fig. 134. Broken Locomotive Link Ready for the Molds
Courtesy of Goldschmidt Thermit Company

Applications of Thermit Welding. The applications of thermit welding are numerous, although the process is better suited to large jobs where the saving in cost of new pieces will justify the cost of the work, Fig. 131. It will be evident also that the process lends itself better to welding large articles than small ones and experience up to the present shows that most thermit welding has been done

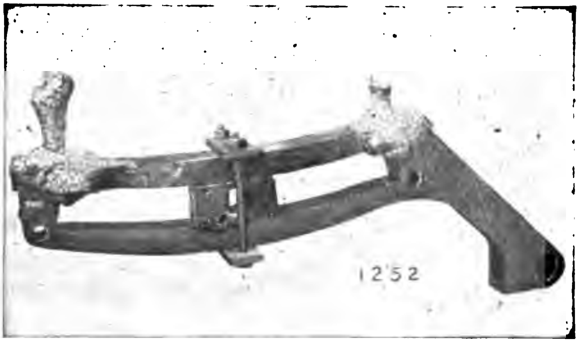


Fig. 135. Welded Locomotive Link with Molds Removed
Courtesy of Goldschmidt Thermit Company

on such large articles as engine and machine tool frames, locomotive side frames, and motor cases. Fig. 132 shows a typical thermit weld at a rail joint. This is a modified Clark joint. Another useful application of the method is in welding stern posts and rudder posts of vessels, Fig. 133. The widest application seems to be in steam railroad shops and, while it is true that the electric arc-welding process is rapidly superseding all others for that service, some of the work done is worthy of description. Considerable saving has been made by doing the work without dismantling the engines in order to get at the break. The process is to form the mold about the break, as described, and set the crucible above it ready for pouring. Where it is possible to lay the article on the floor, as when welding crank shafts or a broken link, Figs. 134 and 135, the job is much easier and quicker to perform.

If the break is in the upper part of a locomotive frame, for example, the break should be cut out about an inch and the frame jacked apart another quarter of an inch. The inch space is for filling and the ¼ inch is to allow for shrinkage; so the jacks should be removed as soon as the mold is filled. Breaks in other parts of locomotive frames are treated in the same way. For welding driving-wheel spokes, it is best to heat the adjacent spokes with a torch to expand before welding the broken ones, and then allow them all to cool at once. Rail welding for street railways is another application of thermit and is clearly shown by the cuts herewith, In all cases it is necessary to clean the metal thoroughly around the joint to remove grease and scale, and this is best done with a sand blast so as to insure bright clean metal to fill against. For work of this nature it pays to provide the fullest equipment in order that there may be no failures, because it is a very expensive operation and very hard to do over again.

Use of Thermit in Other Processes. *Foundry Work.* Other uses of thermit are in foundries for improving the quality of the castings and in metallurgical work to produce metals and alloys free from carbon. In foundries it has been found that, by placing a can of thermit in the ladle before pouring, the temperature of the metal will be raised and, by using thermit of the proper composition, the strength of the metal can be increased or its composition varied to suit different jobs. It is also used in steel mills to reduce losses from "piping" of the ingots. A pipe is a hole formed in the top of the ingot when cooling, due to shrinkage and the presence of slag, and it may extend a considerable distance down into the ingot and reduce its value for rolling. So a can of thermit is thrust down into the top of the ingot at a certain point in the cooling, and this ignites and fuses the steel down and forces the slag out. The mold can then be filled the rest of the way with good steel.

Producing Alloys. The use of thermit, for the production of alloys, etc., has been successful with such metals as titanium, chromium, manganese, vanadium, etc., and alloys of the following compositions have been made.

Ferrotitanium	20–25 % Ti.
Chromium	97–98 % Cr.
Chromium Manganese	30–70 parts
Chromium Copper	10 % Cr.
Chromium Molybdenum	50–50 parts
Manganese	97–98 % Mn.
Manganese Copper	30–70 parts
Manganese Titanium	30–35 % Ti.
Manganese Tin	50–50 parts
Manganese Zinc	20–80 parts
Manganese Boron	30–35 % Bo.
Ferrovanadium	30–35 % Va.
Ferromolybdenum	50–50 parts
Ferroboron	20–25 % Bo.

Ferrotitanium is used as a purifying agent for steel; chromium is used as an alloy with steel to produce crucible steel, etc.; manganese is used to produce very hard steel, bronze alloys, etc.; molybdenum is used in making tool steels; vanadium is used to add to the strength of iron and steel.

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